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REVISION - Draft

LANDSAT Data Continuity Mission LDCM

DRAFT

Operational Land Imager Requirements Document

Landsat Data Continuity Mission

November 2, 2006

Revision - Draft

CM FOREWORD

This document is a Landsat Data Continuity Mission (LDCM) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LDCM CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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Document Revision History

This document is controlled by the LDCM Project Management. Changes require approval of the LDCM Project Manager, LDCM OLI Manager, and the LDCM Mission Assurance Manager. Proposed changes shall be submitted to LDCM Systems Engineering Manager.

RELEASE	DATE	BY	DESCRIPTION
–			Initial Version

List of TBD's/TBC's/TBR's

This document contains information that is complete as possible. Items that are not yet defined are annotated with TBD (To Be Determined). Where final numerical values or data are not available, best estimates are given and annotated TBC (To Be Confirmed). If there is an inconsistency between two requirements then the best estimate is given and annotated with a TBR (To Be Resolved). The following table summarizes the TBD/TBC/TBR items in the document and supplements the revision history.

ITEM	REFERENCE	DESCRIPTION
		Data not supplied

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1 Introduction

1.1 Scope

The Operational Land Imager Requirements Document (OLIRD) establishes the Level 3 procurement requirements for the reflective band sensor for the Landsat Data Continuity Mission (LDCM). As a level 3 document it contains the functional and performance requirements.

1.2 Mission Overview and Requirements Flow

The OLI provides Landsat multi-spectral image acquisition. The inherent goal of the OLI is to serve as a “standard Operational Land Imager” which will be integrated on the LDCM observatory.

OLI will be required to operate nominally on the observatory acquiring multi-spectral scenes (180km x 185km) on a 16 day repeat cycle, on the Worldwide Reference System – 2 with a descending node of 10:00am at a nominal orbit altitude of 705km at the equator.

The general structure of the LDCM Program requirements is shown in Figure 1-1. The flow down represented in this figure identifies which organization controls a set of requirements and who has the authority to change those requirements.

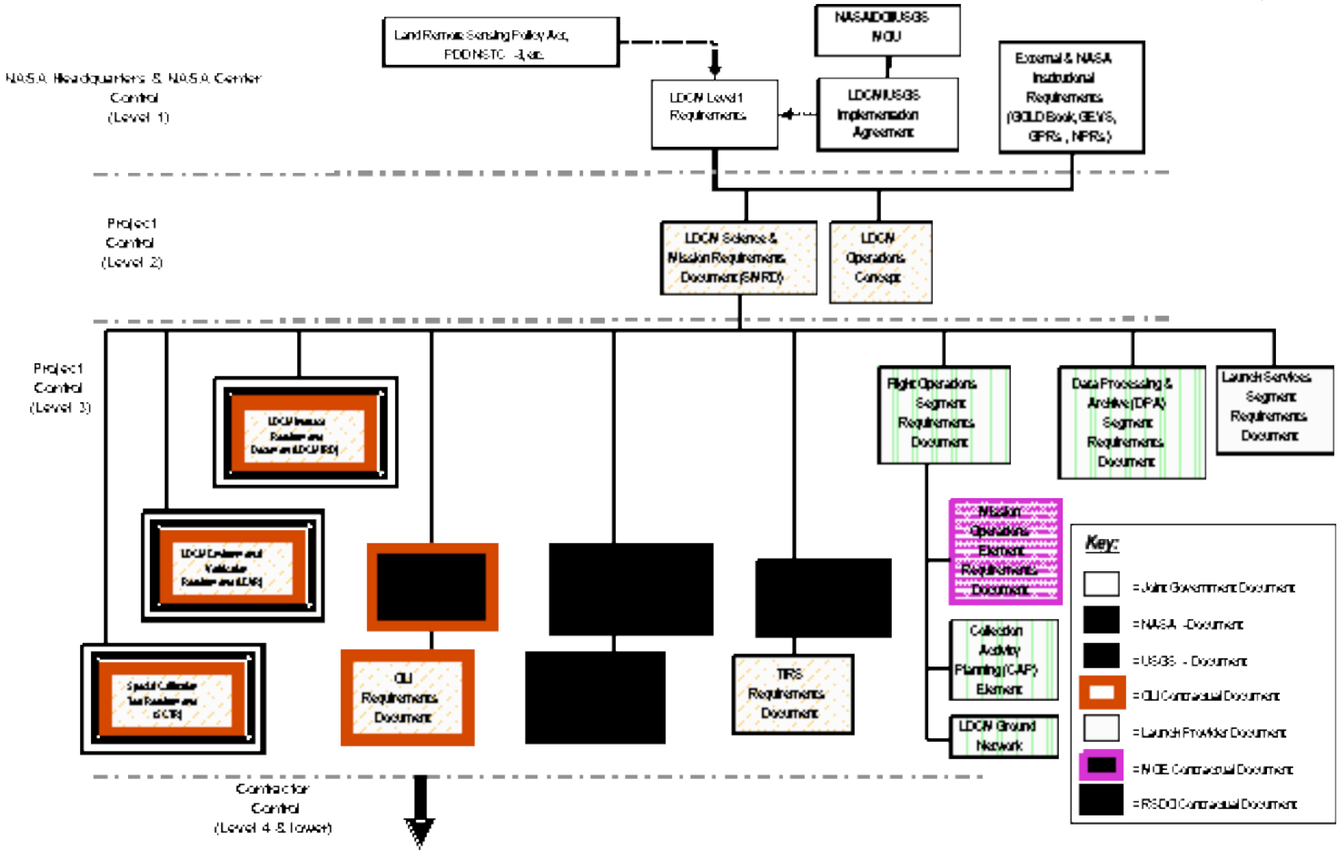


Figure 1.2-1 LDCM Requirements Flow

2 Applicable and Reference Documents

2.1 Applicable Documents

The OLI-RD is consistent with, and responsive to, the following applicable documents of the revision and release date shown. Unless otherwise stated in this document, all inconsistencies in the OLI-RD will be resolved in the following order:

1. LDCM Operational Land Imager Contract
2. LDCM Operational Land Imager SOW
3. LDCM Mission Assurance Requirements
4. LDCM Environmental Verification Requirements Document (LEVR)

Document Number	Revision/ Release Date	Document Title
42 U. S. C., 4321 et seq. NEP	Sept. 13, 1982	National Environmental Policy Act of 1969
AFSPCMAN 91-710 (Vol. 1-7)	July 1, 2004	Air Force Space Command Manual 91-710 Range Safety User Requirements
CCSDS 122.0–B–1	Blue Book, November 2005	Recommendation For Space Data System Standards Image Data Compression
CCSDS 133.0–B-1	September 2003	Recommendation for Space Data Systems Standards TM Space Packet Protocol. Blue Book. Issue 1.
CCSDS 231.0–B–1	September 2003	Recommendation for Space Data Systems Standards. TC Synchronization and Channel Coding. Blue Book. Issue 1.
CCSDS 232.0–B–1	September 2003	Recommendation for Space Data Systems TC Space Data Link Protocol. Blue Book. Issue 1.
CCSDS 232.1–B–1	September 2003	Recommendation for Space Data Systems Standards. Communications Operations Procedure-1. Blue Book. Issue 1.
CCSDS 202.0–B–3	June 2001	Recommendation for Space Data Systems Standards. Telecommand, Part 2: Data Routing Service. CCSDS Recommendation, Blue Book
CCSDS 301.0-B-3	January 2002	Time Code Formats
CCSDS 727.0-B-3	June 2005	CCSDS File Delivery Protocol (CFDP), Blue Book Issue 3
KNPR 8715.3		KSC Safety Requirements

Document Number	Revision/ Release Date	Document Title
NIMA TR8350.2	3rd Edition, Amendment 1, dated 3 January 2000	Department of Defense World Geodetic System 1984
NASA STD-5005	Rev. B, Sept. 15, 2003	Ground Support Equipment
NPD 8010.2	Rev. D, May 14, 2004	Use of the SI (Metric) System of Measurement in NASA Programs
NPD 8710.3	Rev. B, April 28, 2004	NASA Policy for Limiting Orbital Debris Generation
NPR 2810.1A	May 16, 2006	NASA Procedural Requirement, Security of Information Technology

Table 2.1-1 Applicable Documents

2.2 Reference Documentation

The OLI-RD is consistent with the following documents. If the OLI-RD conflicts with the any of these listed documents, the OLI-RD takes precedence.

Document Number	Revision/ Release Date	Document Title
427-xx-xx		Level 1 Requirements for the LDCM Mission
427-xx-xx		Science and Mission Requirements Document
427-xx-xx		OLI Statement of Work
427-xx-xx		Mission Assurance Requirements
427-xx-xx		LDCM Lexicon
427-xx-xx	Rev. -, , 2006	LDCM Environmental Verification Requirements Document (LEVR)
427-xx-xx		LDCM Operations Concept Document
427-xx-xx		Special Calibration Test Requirements (SCTR)
427-xx-xx		LDCM Worldwide Reference System-2 Memorandum
427-XX-XX		Top of Atmosphere Radiance Values Assessment

Table 2.2-1 Reference Documents and Standards

2.3 Literature References

For additional clarification reference is made to documents in the open literature. These documents should be used for clarification and understanding of the requirement. These documents do not constitute additional requirements on the bidder.

Authors	Document Number	Revision/ Release Date	Document Title
[1] S. K. Park and R. A. Schowengerdt,		1983	"Image reconstruction by parametric cubic convolution," Computer Vision, Graphics, and Image Processing, vol. 23, pp. 258-272.
[2] A. Berk, G.P. Anderson, P.K. Acharya, J.H. Chetwynd, L.S. Bernstein, E.P. Shettle, M.W. Matthew, and S.M. Adler-Golden	01731-3010	1 June 1999	MODTRAN4 User's Manual, Air Force Research Laboratory, Space Vehicles Directorate Air Force Materiel Command, Hanscom AFB, MA

3 Functional Overview

3.1 Functional Description

The Operational Land Imager (OLI) is required to provide Landsat multi-spectral image acquisition onboard the LDCM spacecraft for a period of 5 years within the prescribed requirements. The OLI consists of the 9 band reflective sensor. The OLI provides Visible and Near Infrared / Short Wave Infrared (VNIR/SWIR) imagery consistent with Landsat spectral, spatial, radiometric and geometric qualities as specified in Section 5 of this document.

3.2 OLI Functional Element

The OLI includes the optical telescope, Focal Plane Array / Focal Plane Electronics (FPA/FPE) and instrument control electronics. The optical telescope includes the optical bench assembly, baffles and mirrors to gather and focus the optical beam onto the FPA. The FPA/FPE converts photon energy into electrical voltage signals and converts the voltage signals into digital signals. The OLI is specified to provide nine spectral bands with a maximum ground sampling distance, both in-track and cross track, of 30m for all bands except the panchromatic band, which is specified to have a 15m ground sampling distance. The OLI will have a 185km cross track swath width at the mission nominal orbit of 716 ± 12 km altitude and 98.2 ± .05° inclination sun synchronous orbit. The OLI provides both internal calibration sources such as lamps to ensure radiometric accuracy as well as capabilities to perform solar and lunar calibrations within the field of view constraints. The on-board electronics provide the necessary band ordered, data compression necessary to meet the total data rate and data volume of the OLI.

3.3 Mass Memory Functional Element

The Mass Memory or Solid State Recorder (SSR) provides all of the functions necessary to store and as required compress digital image data from the LDCM instruments. The SSR provides the capacity to ingest high rate data streams from the LDCM instruments and data from the spacecraft bus. The SSR will need to temporarily store up to 400 WRS-2 scenes of Mission Data and observatory housekeeping data before this data must be overwritten. Ancillary data includes such items as spacecraft attitude, navigation, timing data and key telemetry values from the sensor and spacecraft. Instrument ancillary data packets provide all necessary image reconstruction information for later ground processing.

The SSR is assumed to be an onboard device that can simultaneously store, process and output the LDCM instrument data streams. Mechanically, the SSR is separate from the other instruments and is likely mounted to the spacecraft bus. This separation is to provide environmental isolation from the LDCM instruments. SSR is expected to ingest image and ancillary data packets and store the data in a time-correlated fashion such that the ancillary data and image data remain time synchronized. Using root filenames assigned by the ground. The ground assigned root filenames will be used for image data, ancillary data (spacecraft and instrument). Mission Data and observatory data stored on the SSR will take advantage of the CCSDS File Delivery Protocol (CFDP). The SSR provides the ability to concurrently store and playback data as necessary to meet the LDCM data collection and downlink requirements. Playback of data will be controlled by ground command. The SSR is expected to provide any necessary error detection and correction to the stored data to prevent degradation due to Single Event Upsets (SEUs) or other space environmental factors. Additionally, the DSAP will provide self-test modes to exercise internal data paths.

4 OLI System Level

4.1 General

The LDCM OLI shall be comprised of the sensor module, all associated sensor control electronics and power modules, all required control, signal processing and data formatting and compression electronics, all required hardware and software to meet sensor performance requirements.

The LDCM OLI shall meet the requirements of the LDCM Observatory Interface Requirements Document, 427-XX-XXX.

The LDCM OLI shall provide the capability to selectively disable any on-orbit processing operation that combines or compresses raw Mission data in any manner.
Rationale: To support early orbit checkout, and for anomaly resolution, by the instrument contractor. Examples of such processing operations are: spatial aggregation of detector

samples; temporal aggregation of detector samples; averaging of detector data acquired while viewing calibration sources; averaging of calibration instrumentation data such as source temperature measurements; and data compression.

The LDCM OLI shall meet LDCM imaging requirements at all points throughout the orbit.
Rationale: Take an image anywhere within the orbit sunlit or eclipse.

The LDCM OLI shall acquire mission data equivalent to 400 individual WRS-2 Scenes, including the in-situ calibration data, per 24 hours.
Rationale: The LDCM OLI will be capable of acquiring sensor image data equivalent to 400 WRS-2 scenes per day plus any necessary calibration data. The 400 WRS-2 scenes account for all image collections in a 24-hour period. Vicarious, lunar, and solar, calibration images are part of the 400 WRS-2 equivalent scenes. In-situ calibration data includes internal sources and blackbody imaging results and is in addition to the 400 scenes. The WRS-2 scenes are actually generated on the ground and not on-orbit.

The LDCM OLI shall operate within the designed operational parameters when the LDCM Observatory points up to 15 degrees, off-nadir, to either side of the current orbit plane.
Rationale: The OLI instrument must remain thermally stable, and fully function in off-nadir pointing attitudes. The image acquisition in this attitude is in lieu of an equivalent amount of nadir WRS-2 path image acquisition.

The LDCM OLI shall acquire up to 5 off-nadir image intervals per day as part of the 400 WRS-2 equivalent OLI instrument data.
Rationale: For rapidly changing conditions on the earth LDCM will be able to image either WRS-2 scenes or off-nadir scenes. These may or may not be a priority interval.

The LDCM OLI shall acquire up to 77 contiguous, sun-lit scenes during any orbit.
Rationale: See the design reference missions in the Operations Concept document which provides the longest possible daylight contiguous land pass.

The LDCM OLI shall acquire up to 38 contiguous, night scenes during any orbit.
Rationale: See the design reference missions in the Operations Concept document which provides a possible lunar imaging scenario for calibration using the moon.

The LDCM OLI shall be commanded by the ground into any operational mode.
Rationale: Operational flexibility but also should not be possible to command the instrument into non-operational (ground test, storage, etc.) modes.

The LDCM OLI shall be in compliance with NASA Policy Directive 8010.2, Use of the SI (Metric) System of Measurement in NASA Programs.

4.1.1 OLI Operational Modes

The LDCM OLI shall implement the following modes and functionalities, as defined herein.
Rationale: This document uses the following definition of OLI modes. Though the OLI contractor is not required to use these same definitions; a mapping of the contractor's OLI modes to these is required.

4.1.1.1 Survival Mode

The LDCM OLI shall implement an Instrument Survival Mode.
Rationale: Survival Mode is entered when a critical power shortage has been identified by the spacecraft. In this low power mode only those functions required for satellite safety, diagnostics and recovery to full operational status will be powered. All instruments on the spacecraft will be reactivated by ground command upon spacecraft recovery.

The LDCM OLI shall enter Instrument Survival Mode without receiving a command from the spacecraft.
Rationale: Survival mode is basically a power off mode and as such the instrument maybe commanded into this mode without any warning. Clearly, it would be better to have the OLI pass through Safe Mode first but that may not always happen.

The LDCM OLI shall receive no external power in the Survival Mode.
Rationale: In this mode the spacecraft will supply survival heater power but that power does not go through any OLI electronics.

The LDCM OLI shall meet all performance specifications after power up following an indefinite period of time in Instrument Survival Mode.
Rationale: The OLI survival is contingent upon power being supplied to the OLI survival heaters. However, it is the OLI contractor who is responsible for sizing and installing OLI survival heaters.

The LDCM OLI shall transition from Instrument Survival Mode to Safe Mode within 45 minutes [TBC].
Rationale: The OLI transition from Instrument Survival Mode to Safe Mode in as short a time as possible within reason to not damage the instrument. This is to maximize the availability of the imaging time.

The LDCM OLI Survival mode shall be used for ground storage and transportation, launch, and spacecraft power crisis situations.
Rationale: The Survival mode is basically the power-off mode for the instrument.

4.1.1.2 OFF Mode

4.1.1.3 Activation Mode

The LDCM OLI shall implement an Activation Mode for instrument turn-on, and subsequent instrument component warm up, or cool down, to its operating temperature.

The LDCM OLI Activation mode shall terminate when all instrument temperatures, biases, and currents have stabilized within specified operational limits.
Rationale: Activation mode includes any deployments and opening of covers or shutters. It is used for the initial power on of the instrument electronics and can be performed while the OLI is in the survival temperature range.

The LDCM OLI shall use the Activation Mode for to enable the command and telemetry functions, and provide for orderly turn-on based on commands to the instrument.

4.1.1.4 Decontamination Mode

The LDCM OLI shall implement a Decontamination Mode in which the instrument is configured to periodically evaporate contaminants which may have been deposited on critical optical surfaces.
Rationale: The LDCM OLI Decontamination Mode is utilized to outgas and evaporate contaminants from the OLI hardware to prevent contamination from jeopardizing performance. In this mode, initial out gassing during the Launch and Early Orbit Phase will occur.

The LDCM OLI Decontamination Mode shall collect and transfer health and status data, but not mission or calibration data.

The LDCM OLI Decontamination Mode shall be exercised at any time during the mission when decontamination is required.

4.1.1.5 Operational Mode

The LDCM OLI shall implement an Operational Mode in which all data collection needed to satisfy the full functional and performance requirements for the instrument are performed.
Rationale: This is the nominal operational mode of the instrument.

The LDCM OLI Operational Mode shall generate the normal mission data, instrument housekeeping telemetry, and periodic calibration information.
Rationale: All allocated spacecraft resources will be available to the instrument in this mode.

The LDCM OLI shall remain in the Operational Mode without damage while the LDCM Observatory performs orbit correction maneuvers.
Rationale: The instrument is not required to meet performance requirements during orbit correction but is not to be damaged by spacecraft maneuvers.

4.1.1.6 Diagnostic Mode

The LDCM OLI shall implement a Diagnostic Mode.

The LDCM OLI Diagnostic Mode shall be used to update or change the fight software.

The LDCM OLI Diagnostic Mode shall be used to update or make changes to housekeeping telemetry format and content.

The LDCM OLI Diagnostic Mode shall be used to update or make changes to different telemetry sampling rates as documented in the LDCM OLI to LDCM Spacecraft ICD.

4.1.1.7 Safe Mode

The LDCM OLI shall implement an Instrument Safe Mode in which OLI is in a fully functional configuration without any science data being collected.
Rationale: This is a safe mode of operations where all instrument constraints (thermal, pointing, etc.) are maintained

The LDCM OLI in Safe Mode shall maintain the design operational environments.
Rationale: This mode maintains operational temperatures and other environment ready for nominal operations.

The LDCM OLI shall transition upon command from Safe Mode to any operational mode or vice versa within 20 seconds.
Rationale: To limit the time needed for OLI transition from various modes. This allows startup and shut down in a reasonable period of time.

The LDCM OLI shall autonomously enter into Safe Mode when an OLI detected failure could result in damage to the OLI.

The LDCM OLI shall notify the spacecraft that it has placed itself into the Safe Mode and await specific further commands via the spacecraft.

The LDCM OLI shall continue to collect and transmit housekeeping data to the spacecraft when in Safe Mode
Rationale: Mission or calibration data would not be automatically transferred to the spacecraft, but it could be if commanded to send the data.

The LDCM OLI shall configure itself such that no damage will occur if the next action from the spacecraft is to turn off the instrument.
Rationale: The contractor may, by choice, utilize this mode as an intermediate state between Operational and Survival Modes.

The LDCM OLI shall enter the Safe Mode by command from the spacecraft.

Rationale: For example this command could be a forwarded ground command, or generated by the spacecraft in response to a power system anomaly. The instrument may also be commanded to enter Safe Mode when the spacecraft is performing scheduled thruster activity, such as for orbit maintenance.

The LDCM OLI shall not over ride or ignore a command to enter Safe Mode.
Rationale: A command to force entry into Safe Mode is not over-ride able by the instrument. The command may originate from the S/C or from the ground

The LDCM OLI shall be capable of autonomously (TBD) transitioning from Safe Mode to the Survival Mode.
Rationale: OLI should be able to power off if there is a problem

The LDCM OLI shall enter Safe Mode upon receipt of a command to enter Safe Mode.
Rationale: There is no autonomous override of the Safe Mode command any conflicts are better resolved after the OLI has been safed.

The LDCM OLI shall enter Safe Mode failing to receive the stored number of consecutive time code data packets from the spacecraft.
Rationale: The OLI will be continuously receiving a time code message unless the S/C C&DH system is down. If the C&DH is down then OLI should be safed.

The LDCM OLI stored number of missed time code packets which result in Safe Mode shall be alterable on-orbit over the range of 1 (TBC) up to a maximum of 63 (TBC) consecutive time code data packets.
Rationale: The value selected to enter Safe Mode will depend on instrument and S/C design.

The LDCM OLI shall enter Safe Mode upon deploying protection for direct solar illumination.
Rationale: In the event the sun is about to enter the OLI aperture the instrument would be most protected in Safe Mode

4.2 OLI System Lifetime

The LDCM OLI shall be designed to operate and meet all design specifications for 5 years beginning after the NASA completes acceptance of the OLI on orbit.
Rationale: Design life starts after acceptance, so instrument commissioning is in addition to the 5 years of operations.

The LDCM OLI shall be designed for an overall Probability of Mission Success of 0.85 [TBC] or greater at the end of design life.
Rationale: End of design life Mission Success is defined as meeting 100% of the minimum mission success requirements at the end of the observatory design life.

4.3 Mission Phases

4.3.1 Storage Phase

The LDCM OLI shall be capable of being placed in a state that does not require intervention by personnel, excluding anomalous events and telemetry monitoring, for 30 day periods.
Rationale: This mode allows for storage of the instrument in the event of delays. This requirement does not preclude the use of N2 or some other purge gas during storage to ensure cleanliness.

4.3.2 Pre-Launch Phase

The LDCM OLI shall be designed for a launch from Vandenberg AFB, CA.

The LDCM OLI shall be compatible with a government furnished payload processing facility at Vandenberg AFB, CA.
Rationale: What ever covers, bagging, purges, etc. are necessary to ensure cleanliness needs to be incorporated in the design.

The LDCM OLI and its Ground Support Equipment used at the launch site shall comply with the US Air Forces Space Command Manual 91-710 Range Safety User Requirements, dated July 1, 2004.
Rationale: Any hazardous systems on the OLI must be in compliance with the Western Range. This includes things like the use of pyrotechnics, pressurized systems, radiation sources, mechanical lift equipment, electrical equipment, etc.

The LDCM OLI shall be designed to be compatible with the Delta II Visible Cleanliness Level – 6.
Rationale: The OLI must meet all performance specifications after exposure to the environments within the launch vehicle fairing. If special protection is required it is the responsibility of the OLI contractor to provide that protection.

The LDCM OLI shall perform aliveness tests while mated to the launch vehicle.
Rationale: To ensure the instrument is ready for launch on pad testing will be performed.

4.3.3 Launch and Early Orbit Phase

The LDCM OLI shall be –launched and remain in the Survival Mode during Launch and Early Orbit Phase of the mission.
Rationale: OLI operations should not interfere with the initial turn-on of the observatory; therefore there should be no need for checking the OLI during the first week of the mission.

The LDCM OLI shall have a launch readiness capability once every 24 hours.
Rationale: To support a launch opportunity every day of the year there should not be any instrument constraints to attempting a launch once every 24 hours.

4.3.4 Commissioning Phase

The LDCM OLI shall be capable of completing commissioning within 30 days.

4.3.5 Operational Phase

Reserved

4.3.6 Decommissioning Phase

The LDCM OLI shall be compliant with NASA Policy Directive NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation.
Rationale: The NPD provides guidelines for minimizing orbital debris. It also invokes NASA Safety Standard NSS 1740.14 for assessing debris and mission survivability. Aperture covers, doors, etc. will not be released as orbital debris and material selection will consider the effects on the re-entry foot print.

4.4 Operational Orbit

The LDCM OLI shall have a 185 km cross track swath width at the mission nominal orbit of 716 ± 12 km altitude and 98.25 ± .05° inclination.
Rationale: The WRS-2 orbit has a nominal equatorial altitude of 705 km. Earth flattening causes the altitude of a circular orbit to vary from 705 km at the equator to just over 726 km at the maximum latitude. Designing the sensor to operate over a range of altitudes from 704 km to 728 km accounts for the effects of Earth flattening and a small amount (~1 km) of orbital variation.

4.5 Redundancy Requirements

The LDCM OLI requirements identified in section 4.5 shall only apply to redundant systems within OLI.

The LDCM OLI shall be designed such that no single credible failure permanently precludes the LDCM OLI from meeting the minimum mission success requirements throughout the observatory design life.

The LDCM OLI shall identify and have compensating provisions for Non-credible single points of failure.

Rationale: This may include such items as design factors of safety, graceful degradation, functional redundancy, etc. Cable harness and pin/socket connections are considered credible failure mechanisms, where an open circuit would result in a single point failure of any required instrument function.

The LDCM OLI shall have no single command that could cause loss of OLI, assuming no OLI components have previously failed.

The LDCM OLI shall provide status of redundant components following processor restart, processor failover, RAM memory loss, or bus under-voltage.
Rationale: This is to prevent the instrument from switching to previously failed components.

The LDCM OLI shall be capable of switching from the prime to the backup unit for redundant systems by ground command.
Rationale: Be able to switch back and forth between prime and backup units through ground commands

The LDCM OLI shall be capable of switching from the backup to the prime unit for redundant systems by ground command.
Rationale: Be able to switch back and forth between prime and backup units through ground commands

The LDCM OLI shall provide status telemetry for all powered redundant systems.

The LDCM OLI shall provide indication for redundant systems of which unit is operating in housekeeping data.

4.6 Autonomy

The LDCM OLI shall autonomously complete transition to its Safe Mode within 45 seconds (TBC) after receiving the command to enter Safe Mode.

The LDCM OLI shall inhibit autonomous Safe Mode entry through a ground command.
Rationale: Ground generated commands can be used to turn-off the automatic transition into Safe Mode by the instrument or from the spacecraft or by other mechanisms documented in the ICD.

The LDCM OLI shall transition out of the OFF Mode, Safe Mode and Survival Mode to an operational mode only via ground command.
Rationale: The instrument can transition to safer modes automatically but up to more complex modes.

The LDCM OLI shall be capable of operating safely without ground intervention for a complete 16-day repeat cycle.

Rationale: In the event there is a failure the OLI can safe its self including power off if necessary. There might not be an imaging schedule but the instrument would survive fine.

The LDCM OLI shall have the ability to autonomously perform reconfiguration of redundant components as required to enter into the Safe Mode or Survival Mode.
Rationale: Ensure that a failure does not propagate or prevent safing of the instrument. There is no requirement for autonomous switching to support nominal operations.

The LDCM OLI shall not autonomously switch to a known failed redundant component.
Rationale: to prevent switching to failed units

The LDCM OLI autonomous functions, automatic safing or switchover shall be over-ridden via ground command.
Rationale: To diagnose failures and anomalies within the instrument

The LDCM OLI shall report autonomous state changes and reconfigurations in housekeeping telemetry.

The LDCM OLI shall report component and subsystem and instrument housekeeping telemetry to observatory housekeeping data.

The LDCM OLI shall not require autonomous reconfiguration for normal operations of the instrument.
Rationale: Autonomous fail over is limited to safing the OLI instrument.

The LDCM OLI shall in the event of an anomaly safely configure the instrument and report the anomaly to the ground in telemetry.

4.7 Availability

The LDCM OLI shall be available for acquiring OLI instrument data that meets the imaging requirements at least 94% [TBC] of the time during a WRS-2 Observation Period.
Rationale: Availability: Orbit Maneuvers of 12 hours / 28 days + Off-Nadir Maneuvers of (5*28*.2) hours / 28 days = 1-40/672 approx. 94%; OLI must support Lunar Cal of 1.6 hour / 28 days + Solar Cal of 1 hour / 28 days

The LDCM OLI shall be capable of continuous operations in the normal Earth pointing attitude for a minimum of 16 days during mission mode.
Rationale:

4.8 Ground Support Equipment

The LDCM Ground Support Equipment (GSE) designed and built or purchased under a LDCM contract shall be in compliance with NASA-STD-5005 Ground Support Equipment.

The OLI GSE shall consist of the following:

a. System Test Equipment (STE)
b. Calibration Test Equipment (CTE)
c. Handling fixtures
d. Test fixtures
e. Shipping / storage containers

The LDCM OLI GSE shall provide an interface to OLI System Test Equipment for real-time data capture and recording of data as received from and transmitted to the LDCM spacecraft.

4.8.1.1 Hardware Interface Simulator (HIS)

The LDCM OLI HIS shall simulate the OLI response to hardware or discrete commands and commands received across the communications bus.

The LDCM OLI HIS shall generate realistic response characteristics for analog telemetry, housekeeping telemetry and mission data.

The LDCM OLI HIS shall provide a flight like OLI instrument interface connection for mating to the LDCM Spacecraft.

4.8.1.2 System Test Equipment (STE)

The LDCM OLI STE shall provide all possible interfaces, e.g., power, clock, command, and telemetry.

The LDCM OLI STE shall be capable of recording, displaying, distributing, and analyzing the data received from the OLI and ground support equipment including all instrument test points.

The LDCM OLI STE shall be capable of real-time data capture and recording all data as received from the OLI and GSE.

The LDCM OLI STE shall be capable of real-time OLI housekeeping and diagnostic data display.

The LDCM OLI STE shall have the capability of generating hard copy print out of all analysis results, screen dumps, and processed data.

The LDCM OLI STE shall have the capability of generating and receiving hard media (e.g., Tape, DVD).

The LDCM OLI STE shall furnish all power, timing signals, and commands needed by the OLI and normally supplied by the spacecraft.

The LDCM OLI STE shall physically isolated all power lines from signal lines.
Rationale: To protect communication circuits from high voltage OLI should use shielded and separate cables.

The LDCM OLI STE power supplies shall have short-circuit protection and voltage-transient protection.

The LDCM OLI STE capabilities shall include:

a. Performing a self-test
b. Sending commands to the instrument
c. Controlling the simulated S/C interfaces and external calibration GSE
d. Receiving data from the OLI, GSE, and test chamber
e. Performing health and safety checks to guarantee the safety of the instrument (in all states)
f. Analyzing the data in real-time and in an off-line mode

The LDCM OLI STE shall be capable of data analysis / processing during testing within 2 hours (exclusive of time required to collect the data).

The LDCM OLI STE shall include engineering and instrument data trending capability and sensor data analysis tools to determine the performance characteristics of the instrument.

The LDCM OLI STE shall simultaneously operate and monitor the instrument and perform data analysis.

The LDCM OLI STE shall display instrument engineering data as well as external GSE data.

The LDCM OLI STE shall have the capability of selecting information to be displayed from a set of pre-stored display templates.

The LDCM OLI STE shall have the capability of displaying test data in SI Units as well as raw digital numbers.

The LDCM OLI STE shall have an operator interface.

The LDCM OLI STE shall provide an interface with the OLI CTE so that data will be entered into the automated data system and correlated (TBD).

The LDCM OLI STE shall operate from a 115-volt, 60-Hertz (Hz) line.

The LDCM OLI STE shall have the capability of monitoring all command states, selected voltages, currents, temperatures, and other telemetered and derived parameters of the OLI and ancillary GSE telemetry in real-time.

The LDCM OLI STE shall monitor OLI Critical Functions.

The LDCM OLI STE shall automatically protect the instrument if appropriate operator action is not taken.

The LDCM OLI STE shall verify all operational modes of the OLI

The LDCM OLI STE shall record and alert the operator of any out-of-tolerance items as they occur.

The LDCM OLI STE shall be capable of bypassing or terminating all automatic sequences resident in the instrument or in the LDCM OLI STE.

The LDCM OLI STE shall operate, at the first application of power during instrument integration and continuing through all periods of operation and/or test, a limits check program.

The LDCM OLI STE shall maintain a command and operational time log.

4.8.1.3 Mechanical Ground Support Equipment (M-GSE)

The LDCM OLI M-GSE shall have the capability of moving and rotating the OLI.

The LDCM OLI M-GSE shall lift the OLI from and return it to its shipping/ storage container.

The LDCM OLI M-GSE shall provide for the integration of the OLI onto the spacecraft.

The LDCM OLI M-GSE shall provide support for the performance verification, environmental testing and calibration of OLI.

4.8.1.4 Shipping/ Storage Containers

The LDCM OLI Shipping & Storage Containers shall be reusable, water-resistant, and airtight with filtered pressure control system.

The LDCM OLI Instrument Shipping & Storage Container shall incorporate means of purging with dry nitrogen or dry air.

The LDCM OLI Instrument Shipping & Storage Container shall incorporate means of measuring and recording shocks, temperature and humidity within the container.

The LDCM OLI Instrument Shipping & Storage Container shall have external indicators for temperature, humidity, and pressure monitoring.

The LDCM OLI Instrument Shipping & Storage Container shall maintain airtight conditions for over 30 days with an internal pressure greater than 1.05 atmospheres.

The LDCM OLI Instrument Shipping & Storage Container shall be capable of being airlifted without loss of internal pressure.

The LDCM OLI Shipping & Storage Containers shall be provided for all other GSE.

The LDCM OLI Shipping & Storage Containers shall be suitable for use in the clean room, after a minimal amount of cleaning.

4.9 Software Simulator

The LDCM OLI Software Simulator shall be capable of operating independently from the Mission Operations Element.

The LDCM OLI Simulator shall integrate into the LDCM Spacecraft Simulator.

The LDCM OLI Simulator shall simulate the operations of the OLI command and data handling system.

The LDCM OLI Simulator shall realistically simulate the OLI response characteristics do to LDCM Spacecraft attitude changes.

The LDCM OLI Simulator shall accurately simulate the inputs of the observatory attitude sensors and the dynamics of the observatory for simulations, such that telemetry responses accurately represent what would be received from the LDCM OLI in flight.

The LDCM OLI Simulator shall simulate the operations of the mass storage system.

The LDCM OLI Simulator shall simulate the operations of the power system.

The LDCM OLI Simulator shall simulate the operations of the telemetry and command response characteristics of the OLI instrument.
Rationale: For FOT training and for OLI instrument software updates, as applicable, the observatory simulator should simulate the appropriate telemetry responses to commands. The mission data is not seen at the MOC so there is no need to include this data in the simulator.

The LDCM OLI Simulator shall interface with the LDCM Spacecraft Simulator.
Rationale: So that the observatory software simulator can talk to the MOE there needs to be a ground station interface. This requirement addresses the fact that the ground RF is not present for the simulator.

The LDCM OLI Simulator shall be capable of simulating all instrument operational modes and mode transitions.

The LDCM OLI Simulator shall verify valid commands, table updates and flight software modifications.

The LDCM OLI Simulator shall receive commands in any flight valid format and data rate.

The LDCM OLI Simulator shall receive, process, and execute flight software updates (including complete version updates, patches, and table updates) that are identical to updates for the flight instrument.

The LDCM OLI Simulator shall accurately simulate the timing of command responses.

The LDCM OLI Simulator shall generate real-time housekeeping telemetry streams with representative instrument data in all valid formats and data rates.

The LDCM OLI Simulator shall simulate the response characteristics of failed instrument subsystems.

The LDCM OLI Simulator shall simulate user defined faults in the instrument.

The LDCM OLI Simulator shall respond to real-time operator changes in the configuration of the simulated instrument.

The LDCM OLI Simulator shall accept inputs from the user to set and change simulation variables.
Rationale: allows users to inject faults, vary initial conditions, etc.

The LDCM OLI Simulator shall accept inputs from the user to set and synchronize simulation time with observatory clock time and ground system time.
Rationale: To synchronize the events on-orbit with the events in the simulation

The LDCM OLI Simulator shall be capable of saving an executed simulation and simulation data.
Rationale: To allow trainers to establish a baseline set of training simulations and be able reproduce a simulation

The LDCM OLI Simulator shall be capable of running a previous executed simulation.
Rationale: To allow trainers to establish a baseline set of training simulations and be able reproduce a simulation

4.10 Software Development and Verification Facility

The LDCM Software Development and Verification Facility (SDVF) shall include Engineering Test Unit versions of the LDCM OLI command and data handling processor, and the power control/ distribution system and other hardware necessary to replicate the flight hardware needed for software development, verification, and anomaly resolution purposes.
Rationale: The SDVF needs to consist of the proper hardware to accurately simulate OLI behavior for anomaly resolution, and to maintain and update flight software over an extended operational period of the mission.

The LDCM SDVF shall be self contained and not require additional software or hardware to perform LDCM flight software development and verification.
Rationale: SDVF may consist of a suite of tools, compilers, de-buggers, performance assessment tools, etc. but should be all within one facility. These tools should remain under configuration control equivalent to the flight software.

5 Imagery Requirements

5.1 General

This section establishes the requirements for image characteristics and image quality to be provided by the Operational Land Imager. This section also describes the requirements for image correction that are necessary in order to verify Operational Land Imager performance.

The LDCM OLI shall have a minimum field of view that provides a 185 km cross-track swath width at the equator for the LDCM operational orbit.
Rationale: This is a nominal value assessed at the equator. For the poles the cross-track cover will be larger.

The LDCM OLI image requirements only apply to nadir imaging.
Rationale: Off-nadir images are important to the mission requirements of LDCM but do not drive the instrument performance. It would be nice if the processing algorithms could

correct for the off-nadir pointing. The requirements on OLI concerning off-nadir are to ensure that the instrument design operates reliably and off-nadir does not impact the nadir operational life of the instrument.

5.2 Data Compression and Non-uniformity Correction

If the LDCM OLI implements an image data compression to keep from exceeding the maximum data playback rate, then the requirements of section 5.2.1 shall apply.
Rationale: If data compression is required to reduce the total volume of image then it needs to be back out once the data is back on the ground.

If the LDCM OLI implements a non-uniformity correction on the image data in support of data compression, then the requirements of section 5.2.2 shall apply.
Rationale: If NUC is required to improve the compressibility of the image data then it needs to be back out once the data is back on the ground.

5.2.1 Image Data Compression

The LDCM OLI data compression algorithm applied to OLI image data or ancillary data shall be lossless.

The LDCM OLI data compression algorithm shall be commandable on and off.

The LDCM OLI data compression algorithm shall be performed in either the Solid State Recorder or in the OLI instrument electronics.
Rationale: It is the data rate to the ground that must not be exceeded. If there are advantages to compressing data before the SSR that is fine.

5.2.2 Image Data Non-uniformity Correction (NUC)

The LDCM OLI NUC algorithm implemented shall be fully reversible.

The LDCM OLI NUC algorithm implemented shall be reconfigurable to allow for updates.

The LDCM OLI shall record and transmit the NUC coefficients used with each image data file.

The LDCM OLI shall receive and implement updated NUC coefficient data.

5.3 Data Processing Algorithms

The following section describes the allowable set of data processing algorithms required to make corrections to the LDCM mission data; to detect, evaluate and correct systematic errors in the LDCM data; and to use government-provided support data to correct

residual errors in the LDCM data so that the resulting corrected LDCM data meet the imagery requirements of sections 5.6 and 5.7.
Rationale: This limitation is to prevent the use of an open-ended “fix it on the ground” approach that would allow, for example, image-based band registration correction methods. Such methods tend to be highly data dependent making in difficult to verify that performance requirements are met in general rather than only for selected test data sets.

5.3.1 Radiometric Correction Algorithms

Information: The radiometric correction algorithms correct the raw detector sample data, mission data, so that the radiometrically corrected LDCM data meet the radiometric performance requirements in sections 5.6.1, 5.6.2.3 and 5.6.5.

5.3.1.1 Detector Bias Determination

The detector bias determination algorithm shall calculate the appropriate bias level for subtraction from each detector for the subsequent conversion to reflectance or radiance.
Note: Historical bias data and/or bias trends, focal plane temperatures, temperature sensitivity coefficients, simultaneous dark detector data, and/or pre and post interval dark image data may be used as necessary for bias determination.

5.3.1.2 Conversion to Radiance

The conversion to radiance algorithm shall take the raw output of each detector in digital numbers and convert it to spectral radiance (W/m^2-sr-μm) using the detector-by-detector bias levels from 5.3.1.1, and previously derived gain coefficients.
Note: Radiometric corrections may include sensitivities to ancillary data, e.g., Gain = C_1e^{c2T} or Gain = $C_1 + C_2X + C_3Y$ where C_1, C2 and C_3 are considered gain coefficients and T, X and Y are ancillary data inputs.

5.3.1.2.1 Conversion to Radiance Algorithm Restrictions

The conversion to radiance algorithm shall not rely on the content of the specific scene being corrected to determine the gain corrections.

5.3.1.3 Conversion to Reflectance

The conversion to reflectance algorithm shall take the raw output of each detector in digital number and convert it to TOA fractional reflectance using the detector-by-detector bias levels from 5.3.1.1, and previously derived absolute and relative gain coefficients.

5.3.1.3.1 Conversion to Reflectance Algorithm Restrictions

The conversion to reflectance algorithm shall not rely on the content of the specific scene being corrected to determine the gain corrections.

5.3.1.4 Inoperable Detector Replacement

The inoperable detector replacement algorithm shall replace the responses from detectors failing to meet the requirements for operability with values estimated from the surrounding detectors.

5.3.1.4.1 Inoperable Detector Replacement Methods

The inoperable detector replacement algorithm shall provide selectable replacement methods including, but not limited to: nearest-neighbor replacement or linear interpolation replacement.

5.3.2 Geometric Correction Algorithms

The algorithms which correct for georegistration, geolocation and other geometric effects register radiometrically corrected LDCM data to an absolute Earth coordinate reference system so that the resulting geometrically corrected LDCM data meet the geometric and geolocation performance requirements in section 5.7.

5.3.2.1 Ancillary Data Preprocessing

The ancillary data preprocessing algorithm shall operate on the LDCM ancillary data to detect and correct erroneous ancillary data, perform units rescaling and coordinate system conversions, and apply ancillary data calibration corrections (e.g., clock correction, response/transfer function compensation, temperature sensitivity compensation). Auxiliary calibration parameters, quality thresholds, and other reference data sets may be used in this process.

Information: The resulting corrected LDCM ancillary data are used by subsequent geometric correction algorithms.

5.3.2.2 Line-of-Sight (LOS) Model Creation

The LOS model creation algorithm shall use preprocessed ancillary data in conjunction with auxiliary calibration parameters to construct a model that relates each LDCM pixel line-of-sight to an absolute Earth-referenced coordinate system, such as Earth Centered Inertial of Epoch J2000.

5.3.2.2.1 LOS Model Creation Algorithm Restrictions

The LOS model creation algorithm shall not use image-derived measurements to improve accuracy.

5.3.2.3 Line-of-Sight Projection

The LOS projection algorithm shall use the LDCM LOS model in conjunction with the WGS84 G1150 or current version, Earth model to intersect each pixel line-of-sight with the Earth's surface, as defined in the following sections.

5.3.2.3.1 LOS Projection to the Earth Ellipsoid Surface

The LOS intersection algorithm shall intersect each pixel line-of-sight with the WGS84 Earth ellipsoid surface.

5.3.2.3.2 LOS Projection to the Terrain Surface

The LOS intersection algorithm shall intersect each pixel line-of-sight with the Earth's topographic surface as defined by government-furnished digital elevation data accurate to 12 meters (90% linear error).

5.3.2.3.3 LOS Projection Algorithm Restrictions

The LOS intersection algorithm shall not use image-derived measurements to improve accuracy.

5.3.2.4 Line-of-Sight Model Correction

The LOS model correction algorithm shall use measurements of government-provided ground control points in the radiometrically corrected LDCM imagery to correct residual systematic errors in the LOS model constructed using the LDCM ancillary and calibration data, as described in section 5.3.2.2.

The government-provided ground control points will be accurate to 3 meters (90% circular error) horizontally and 12 meters (90% linear error) vertically, with 5 or more points distributed in the along- and cross-track directions across the WRS-2 scene area.

5.3.2.4.1 LOS Model Correction Algorithm Restrictions

The LOS model correction algorithm shall not use ground reference data beyond that provided by the government.

5.3.3 Image Resampling

The image resampling algorithm shall interpolate at-sensor radiance values for Earth-referenced sample points from the radiometrically corrected LDCM image data.

5.3.3.1 Input Image to Resampled Output Image Mapping

The image resampling algorithm shall use the line-of-sight projection algorithms of 5.3.2.3 to geometrically remap the input radiometrically corrected detector samples from 5.3.1 to an output Earth-referenced map projection coordinate system.

5.3.3.2 Resampling Interpolation Method

The image resampling algorithm shall use the cubic convolution algorithm [reference 1] for image interpolation.

5.3.4 Data Processing Algorithm Performance

The radiometric correction algorithms of section 5.3.1 and the geometric correction algorithms of section 5.3.2 shall create a radiometrically and geometrically corrected LDCM image (all spectral bands) for a WRS-2 scene-sized area, at the nominal ground sample distance for each spectral band, using one commercially available off-the-shelf workstation, in 2 hours or less.

5.4 Spectral Bands

5.4.1 Spectral Band passes

5.4.1.1 Spectral Band Edges

The band edges for each spectral band shall fall within the range of the minimum lower band edge and the maximum upper band edge as listed in Table 5.4-1.

Note: The Full-Width-Half-Maximum (FWHM) points of the relative spectral radiance response curve define the bands edges for each spectral band. The shortest wavelength with 0.5 of peak relative response is the lower band edge; the longest wavelength with 0.5 of peak relative response is the upper band edge.

5.4.1.2 Center Wavelength

The center wavelength of the spectral response, i.e. the mid-point between the band's upper and lower band edges, shall be the values listed in Table 5.4-1 within the specified tolerances also listed in Table 5.4-1.

Table 5.4-1 Spectral Bands

#	Band	Center Wavelength (nm)	Center Wavelength Tolerance (±nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)

#	Band	Center Wavelength (nm)	Center Wavelength Tolerance (±nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)
1	Coastal Aerosol	443	2	433	453
2	Blue	482	5	450	515
3	Green	562	5	525	600
4	Red	655	5	630	680
5	NIR	865	5	845	885
6	SWIR 1	1610	10	1560	1660
7	SWIR 2*	2200	10	2100	2300
8	Panchromatic **	590	10	500	680
9	Cirrus	1375	5	1360	1390

* Minimum bandwidth is 180 nm for band 7
** Minimum bandwidth is 160 nm for the panchromatic band

5.4.2 Spectral Band Shape

5.4.2.1 Spectral Flatness

5.4.2.1.1 Flatness Between Band Edges

The relative spectral radiance response between the lower band edge (lowest wavelength with 0.5 of peak relative response) and the upper band edge (highest wavelength with 0.5 of peak relative response) is required to have the following properties:

5.4.2.1.1.1 Average Response

The average relative spectral radiance response shall be greater than 0.8.

5.4.2.1.1.2 Minimum Response

No relative spectral radiance response shall be below 0.4.

5.4.2.1.2 Flatness Between 0.8 Relative Response Points

The relative spectral radiance response between the minimum wavelength within the band with a 0.8 relative response point and the maximum wavelength within the band with a 0.8 relative response point shall always exceed 0.7.

5.4.2.2 Out of Band Response

5.4.2.2.1 Beyond 0.01 Relative Response Points

The ratio of the integrated relative spectral radiance response outside the 0.01 response points of each defined spectral band to the integrated relative spectral radiance response between the 0.01 response points of each defined band shall be less than 2%.

Note: The 0.01 relative response points are the points closest to the center wavelength where the relative response first drops to 0.01 of the peak relative response on each side of the center wavelength. The integrated responses will be weighted by the solar TOA irradiance. The MODTRAN 4 "Chkur" solar spectrum will be used for this calculation [reference 2, Section 2.3]. Electrical crosstalk is not included within this requirement.

5.4.2.2.2 Response at Outer Wavelengths

5.4.2.2.2.1 VNIR and Cirrus

For bands 1, 2, 3, 4, 5 8 and 9, the value of the out of band relative spectral response at wavelengths lower than the lower band edge of the FWHM point minus 50 nm and the wavelengths higher than the higher band edge of the FWHM point plus 50 nm shall not exceed 0.001. Electrical crosstalk is not included within this requirement.

5.4.2.2.2.2 SWIR

For bands 6,7, and 8 the value of the out of band relative spectral response at wavelengths lower than the lower band edge of the FWHM point minus 100 nm and the wavelengths higher than the higher band edge of the FWHM point plus 100 nm shall not exceed 0.001. Electrical crosstalk is not included within this requirement.

5.4.3 Relative Spectral Response Edge Slope

5.4.3.1 Wavelength Intervals – Case 1

The wavelength interval between the first 0.05 and the first 0.5 relative spectral response points and the last 0.5 and the last 0.05 relative response points shall not exceed the values in Table 5.4-2.

5.4.3.2 Wavelength Intervals – Case 2

The wavelength interval between the first 0.01 and the first 0.5 relative spectral response points and the last 0.5 and the last 0.01 relative response points shall not exceed the values in Table 5.4-2.

Table 5.4-2 Spectral Edge Slope Intervals for Reflective Bands

#	Band	Lower Edge Slope Interval 0.01 to 0.50* (nm)	Lower Edge Slope Interval 0.05 to 0.50* (nm)	Upper Edge Slope Interval 0.50 to 0.05* (nm)	Upper Edge Slope Interval 0.50 to 0.01* (nm)
1	Coastal Aerosol	15	10	10	15
2	Blue	25	20	20	25
3	Green	25	20	20	25
4	Red	25	20	15	20
5	NIR	25	20	15	20
6	SWIR 1	40	30	30	40
7	SWIR 2	50	40	40	50
8	Panchromatic	50	40	40	50
9	Cirrus	15	10	10	15

* Normalized to peak spectral response for the band

5.4.4 Spectral Uniformity

Within a band the measured FWHM bandwidths for each detector shall be within ±3% of the measured mean FWHM bandwidth.
Note: Section 5.6.2.3 imposes additional spectral uniformity requirements.

5.4.5 Spectral Stability

Band center wavelengths and band edges shall not change by more ± 2 nm over the life of the mission.

5.4.6 Spectral Band Simultaneity

For any point within a single WRS-2 scene, the imaging sensor shall acquire data for bands 1 through 9 within a 1.5 second period.

5.5 Spatial Performance

5.5.1 Reflective Band Ground Sample Distance

5.5.1.1 Multispectral Bands

5.5.1.1.1 Pixel-to-Pixel Increment

OLI instrument data shall provide a pixel-to-pixel increment, in the in-track and cross-track directions, equivalent to a Ground Sampling Distance (GSD) less than or equal to 30 m across the WRS-2 scene for bands 1, 2, 3, 4, 5, 6, 7 and 9.

5.5.1.2 Panchromatic Band

OLI instrument data shall provide a single panchromatic band with a pixel-to-pixel increment, in the in-track and cross-track directions, equivalent to a GSD less than or equal to 15 m across the WRS-2 scene.

5.5.2 Edge Response

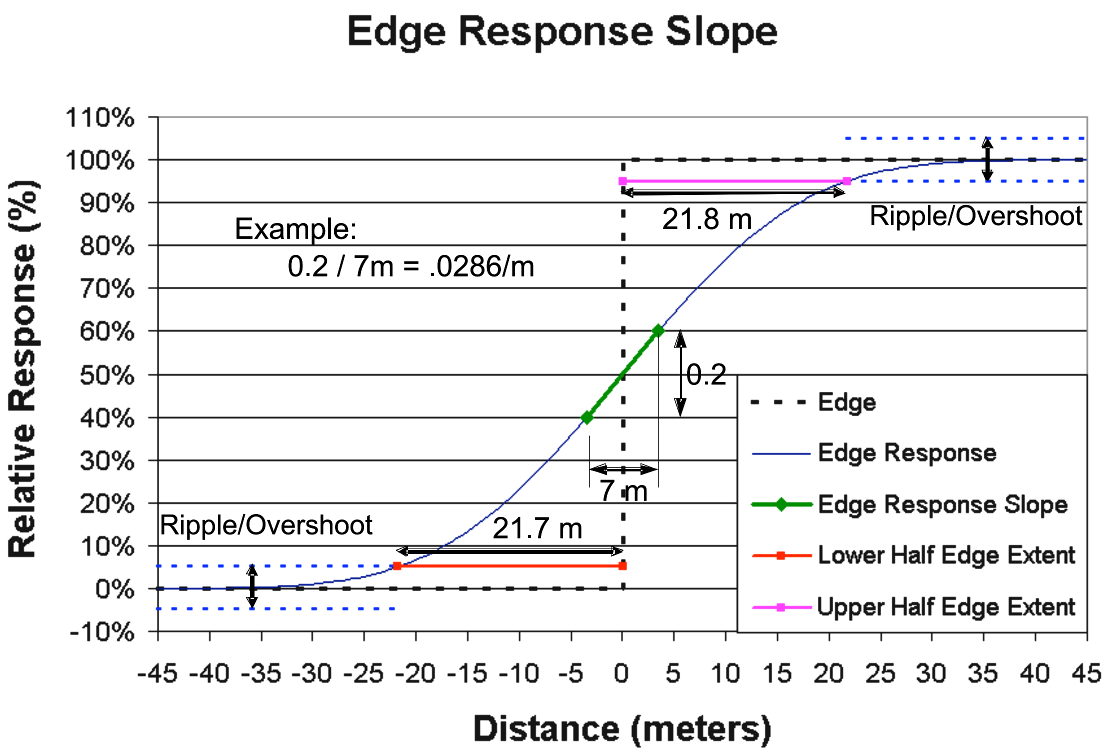
The relative edge response in the in-track and cross-track directions for radiometrically corrected sensor data, per paragraph 5.3.1.2, shall conform to the criteria described in the following subsections.

Note: Table 5.5-1 lists the bands, their maximum allowable GSD, and the minimum edge slope and maximum half edge extent of the edge response. The edge response, in the context below, is the normalized response of the imaging system to an edge. That is, the edge response is normalized so that the mean low-side steady state edge response is set to zero and the mean high-side steady state edge response is set to 100%.

Table 5.5-1 GSD, Minimum Edge Slope and Maximum Half Edge Extent Specifications

#	Band	Maximum GSD	Minimum Slope	Maximum Half Edge Extent
1	Coastal Aerosol	30 m	.027 / m	23.0 m
2	Blue	30 m	.027 / m	23.0 m
3	Green	30 m	.027 / m	23.0 m
4	Red	30 m	.027 / m	23.5 m
5	NIR	30 m	.027 / m	24.0 m
6	SWIR 1	30 m	.027 / m	28.0 m
7	SWIR 2	30 m	.027 / m	29.0 m
8	Panchromatic	15m	.054 / m	14.0 m
9	Cirrus	30m	.027 / m	27.0 m

Figure 5.5-1 Relative Edge Response



5.5.2.1 Response Slope

The relative edge response slope for the OLI bands shall exceed the values shown in Table 5.5-1 for radiometrically corrected OLI instrument data, per paragraph 5.3.1.2, across the entire field-of-view.

Note: The relative edge response slope is defined as the slope between the 40% and 60% response points as depicted in Figure 5.5-1.

Rationale: Edge slope captures the primary optical and electrical effects that constrain image spatial performance. Edge slope is chosen as the key specification here over MTF so that the specifications can be expressed in absolute ground units (meters) independent of the ground sample distance, so that over sampling is not discouraged as it can be with specifications that scale with the sample distance. Edge response is also more amenable to direct measurement/characterization than is MTF which is usually computed analytically based on edge or impulse measurements.

5.5.2.2 Half Edge Extent

The upper half edge extents and the lower half edge extents for the OLI spectral bands shall be less than the maximum half edge extent values shown in Table 5.5-1 for radiometrically corrected image sensor data, per paragraph 5.3.1.2, across the entire field-of-view.

Note: The lower half edge extent is defined as the horizontal distance, in meters, between the 5% and 50% relative response points as depicted in Figure 5.5-1. The upper half edge extent is defined as the horizontal distance, in meters, between the 50% and 95% relative response points as depicted in Figure 5.5-1.

Rationale: Imaging system simulations have shown that certain types of image degradations (e.g., ghost images with small displacements) can significantly degrade the overall edge response performance even when their effect on the central 40%-60% portion of the edge is minimal. Including a specification that covers more of the edge better protects against this type of localized degradation. The upper and lower half edge extents are both used to protect against artifacts that only effect one side of the edge.

5.5.2.3 Edge Response Overshoot

The overshoot of any edge response for all bands shall not exceed 5% for OLI instrument data.

Note: Overshoot applies to both the high (100% response) and low (0% response) sides of the edge so that the maximum response is less than 105% and the minimum response is greater than -5%.

5.5.2.4 Edge Response Ripple

Edge response ripple for all bands shall not exceed 5% for image sensor data.

Note: Ripple applies to both the high (100% response) and low (0% response) sides of the edge so that the response is greater than 95% beyond the 95% response point and the response is below 5% beyond the 5% response point.

5.5.2.5 Edge Response Uniformity

The relative edge response slope shall not vary by more than 10% (maximum deviation from the band average) in any band across the field-of-view and by not more than 20% (maximum deviation from the multi-band average) between spectral bands 1, 2, 3, 4, 5, 6, 7, and 9 for OLI instrument data.

Rationale: This specification ensures consistent spatial performance across the field of view and across the spectral bands to reduce application performance sensitivity to target location within the FOV and control spectral mixing due to spatial effects.

5.5.3 Aliasing

The product of the relative edge response slope and the GSD provided by OLI instrument data shall be less than 1.0 for both the in-track and cross-track directions.

Rationale: This specification protects against data undersampling by ensuring that the sample spacing (GSD) is commensurate with the actual edge slope performance.

5.5.4 Light Rejection and Internal Scattering

Definition: A light rejection scene or a scene to assess internal light scattering is defined as follows:

- The OLI instrument data are collected from a circular region having a radius = 0.25 degrees and having a uniform target radiance = LT.
- That target region is surrounded by an annular region having an inner radius = 0.25 degrees and an outer radius = 25 degrees and having a uniform background radiance = LB.
- When LB = LT, the OLI instrument data radiance measured at the center of the target region has a nominal value = LT.

All angles are measured relative to the sensor nadir view.

The magnitude of the change in the OLI instrument measured radiance for all spectral bands at the center of the light rejection scene shall be less than 0.004 times the magnitude of the difference between LB and LT, where target and background radiance levels range from a minimum of zero to a maximum of LMax, such that LT - LB ranges from a minimum of -LMax to a maximum of + LMax.

Note: This requirement applies to all spectral bands for the duration of the nominal observatory design life for target and background radiance levels ranging from a minimum of zero to a maximum of LMax, such that LT - LB ranges from a minimum of -LMax to a maximum of + LMax.

5.5.5 Ghosting

An extended object at a radiance level just below the detectors saturation level, anywhere in the OLI instrument telescope full FOV, shall not produce a significant (as described below) ghost image anywhere in the active detectors area of the focal-plane. This requirement applies to all spectral bands across the entire focal plane.

Note: A ghost image is either a secondary image of an object within the FPA FOV or an image of an object that is outside the FPA FOV. In either case the ghost appears as either an attenuated rendition of the original object or a blurred and attenuated version of the original object. A ghost also has a constant displacement vector from the original image. A significant ghost is defined as an image artifact when its peak signal after background level subtraction and radiometric calibration is above 2% of the typical radiance (L_{typ}) for that band. This restriction is intended to prevent ghosting from significantly affecting the radiometric errors during normal operations.

5.6 Radiometry

5.6.1 Absolute Radiometric Uncertainty

The OLI instrument absolute radiometric uncertainty requirements are given in Table 5.6-1 for the range of $L_{typical}$ to 0.9 L_{max} (Table 5.6-2). At any other radiance across the range of 0.3 $L_{typical}$ to $L_{typical}$ the absolute uncertainty shall not exceed the values in Table 5.6-1 by more than 0.5%. This requirement applies to extended, spatially uniform, unpolarized targets with a known spectral shape.

Pre-launch radiance uncertainties shall be established relative to National Institute for Standards and Technology (NIST) standards.

Uncertainty estimates shall include the NIST standard uncertainties.

Table 5.6-1 Absolute Radiometric Uncertainty Requirements

Parameter	Requirement (1-sigma)
Radiance	5%
Top of Atmosphere (TOA) Reflectance	3% of actual TOA

Table 5.6-2 Radiance Levels for Signal-to-Noise Ratio (SNR) Requirements and Saturation Radiances

#	Band	Radiance Level for SNR, L (W/m^2 sr µm)		Saturation Radiances, L_{Max} (W/m^2 sr µm)
		Typical, $L_{Typical}$	High, L_{high}	Requirement
1	Coastal Aerosol	40	190	555
2	Blue	40	190	581
3	Green	30	194	544
4	Red	22	150	462
5	NIR	14	150	281
6	SWIR 1	4.0	32	71.3
7	SWIR 2	1.7	11	24.3
8	Panchromatic	23	156	515

9	Cirrus	6.0	N/A	88.5

5.6.2 Radiometric Signal-to-Noise and Uniformity

5.6.2.1 Detector Signal-to-Noise Ratios (SNRs)

The median SNRs required for all OLI data for each spectral band shall be as listed in Table 5.6-3**.**

a.) 50% of all detectors for each band shall meet or exceed these SNR values.
b.) Any detector below 80% of these values shall be considered out-of-specification per paragraph 5.6.7.4.

Table 5.6-3 SNR Requirements

#	Band	SNR Requirements	
		At $L_{Typical}$*	At L_{High}*
1	Coastal Aerosol	130	290
2	Blue	130	360
3	Green	100	390
4	Red	90	340
5	NIR	90	460
6	SWIR 1	100	540
7	SWIR 2	100	510
8	Panchromatic	80	230
9	Cirrus	50	N/A

* - see Table 5.6-2 for definition of $L_{Typical}$ and L_{High}

5.6.2.2 OLI Data Quantization

OLI data shall be quantized to 12 bits.

OLI data SNR performance shall not be quantization noise limited at $L_{typical}$ and above, i.e., system noise is greater than or equal to 0.5 Digital Number, unless meeting this requirement would force greater than 12 bit quantization.

5.6.2.3 Pixel-to-Pixel Uniformity

The following environmental conditions and measurement approach shall apply to requirements 5.6.2.3.1, 5.6.2.3.2, and 5.6.2.3.3.

- The requirements shall apply for uniform sources with the radiance level above $2*L_{typical}$
- The radiometric values shall be corrected per paragraph 5.3.1.2.
- Temporal noise shall be averaged to verify compliance with this specification.
- Target radiances with spectral characteristics as follows:
    - Spectral radiance from bare desert soil as observed through a dry atmosphere (excluding band 9)
    - Spectral radiance proportional to the TOA solar irradiance
    - Spectral radiance from a dense vegetation target as observed through a moist atmosphere (excluding band 9)
    - These spectral radiances are shown in Figure 5.6-1 and given in "Top of Atmosphere Radiance Values, MODTRAN 4 Model" table values, see LDCM 427-XX-XX Top of Atmosphere Radiance Values.
- Target radiances are all determined using the same gain calibration coefficients.

5.6.2.3.1 Full Field of View

The standard deviation of the radiometrically corrected values across all pixels within a line of OLI data within a band shall not exceed 0.25% of the average radiance.

This requirement is met when:

$$\sqrt{\frac{\sum_{i=1}^{N}(\overline{L}_i - \overline{L}')^2}{N-1}} \le 0.0025 \cdot \overline{L}'$$

Where:

$\overline{L}_i$ is the temporal average response of pixel i;

$\overline{L}'$ is the 2 dimensional (temporal first and then spatial) average response for a spectral band;

N Total number of pixels in a spectral band line.

5.6.2.3.2 Banding

a. The root mean square of the deviation from the average radiance across the full line for any 100 contiguous pixels within a line of radiometrically corrected OLI instrument data within a band shall not exceed 0.5% of that average radiance.

This banding requirement is met when, for all n:

$$\sqrt{\sum_{i=n}^{n+99}(\overline{L}_i - \overline{L}')^2 / 100} \le 0.005 \cdot \overline{L}'$$

Where:

n is the pixel number in a line of data;

$\overline{L}_i$ is the temporal average response of pixel i;

$\overline{L}'$ is the 2 dimensional (temporal first and then spatial) average response for a spectral band.

b. The standard deviation of the radiometrically corrected values across any 100 contiguous pixels within a line of OLI instrument data within a band shall not exceed 0.25% of the average radiance across the full line. The average radiance across the line (FOV) is used here merely as a reference for deriving the magnitude of the 0.25%. The mean in the standard deviation calculation is, by definition, the mean of the 100 pixel sample set and not the entire FOV mean.

This banding requirement is met when for all n:

$$\sqrt{\sum_{i=n}^{n+99} (\overline{L}_i - \overline{L})^2 / 99} \quad \leq 0.0025 \cdot \overline{L}'$$

Where:

n is the pixel number in a line of data;

$\overline{L}_i$ is the temporal average response of pixel i;

$\overline{L}$ is the average calibrated detector response across the 100 pixel sample set in radiance units

$$\overline{L} = \sum_{i=n}^{n+99} L_i / 100$$

$\overline{L}'$ is the 2 dimensional (temporal first and then spatial) average response for a spectral band.

5.6.2.3.3 Streaking

The maximum value of the streaking parameter within a line of radiometrically corrected OLI instrument data shall not exceed 0.005 for bands 1-7 and 9, and 0.01 for the panchromatic band.

The streaking parameter is defined by the following equation:

$$S_i = \left| \overline{L}_i - \frac{1}{2}\left(\overline{L}_{i-1} + \overline{L}_{i+1}\right) \right| / \overline{L}_i$$

Where:

$\overline{L}_i$ is the temporal average calibrated radiance value measured for pixel I;

$\overline{L}_{i-1}$ and $\overline{L}_{i+1}$ are similarly defined for the (i–1)th and (i+1)th pixels.

5.6.2.3.4 Temporal Stability

The requirements of section 5.6.2.3.1- 5.6.2.3.3 shall be met for the 7-day period extending forward in time from the calibration update using the same gain calibration coefficients.

Note: Bias determination can be performed during the 7-days per paragraphs 5.3.1.1. Gain calibration coefficients may include a dependency on parameters including instrument temperatures and voltages.

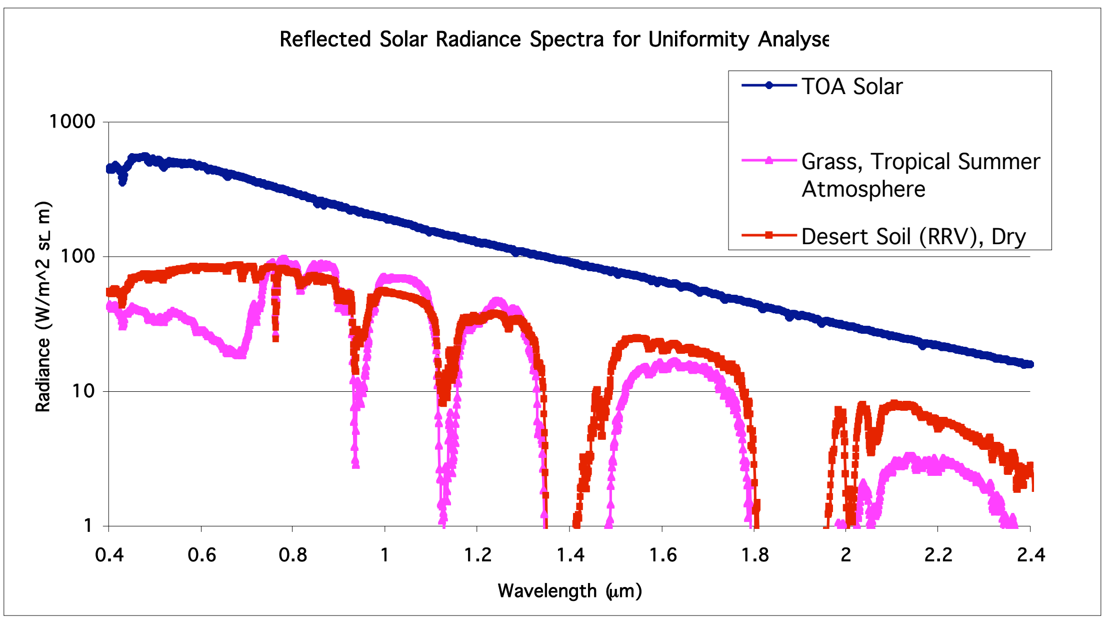


Figure 5.6-1 Top of Atmosphere Spectra for Uniformity Analyses

5.6.2.4 Coherent Noise

Each pixel column in a uniform scene or dark background image in any band acquired by the OLI instrument, after radiometric calibration per 5.3.1.2, shall only contain coherent noise (CN) components with relative percentage amplitude (DN%), that are lower than the $DN\%_{max}$ level denoted by the following formula (see Figure 5.6-2):

$DN\%_{max}(f) = 9.0\ f + 1.9.$

Where:
f is frequency in cycles/pixel;
$DN\%_{max}$ is in %.

The DN% is given by the ratio of the individual CN component zero-to-peak amplitude to 3 times the standard deviation of a full WRS-2 scene-sized area, i.e.,

DN% = (Amplitude of Coherent component) / (3 times the standard deviation of the image)*100%

Note: the individual CN component amplitude is the amplitude of the wave pattern generated, for example, in the model of a sine wave it will be the amplitude of a sine wave defined as Asin(b+phase). Pixels failing this specification will be considered out-of-spec per paragraph 5.6.7.4.

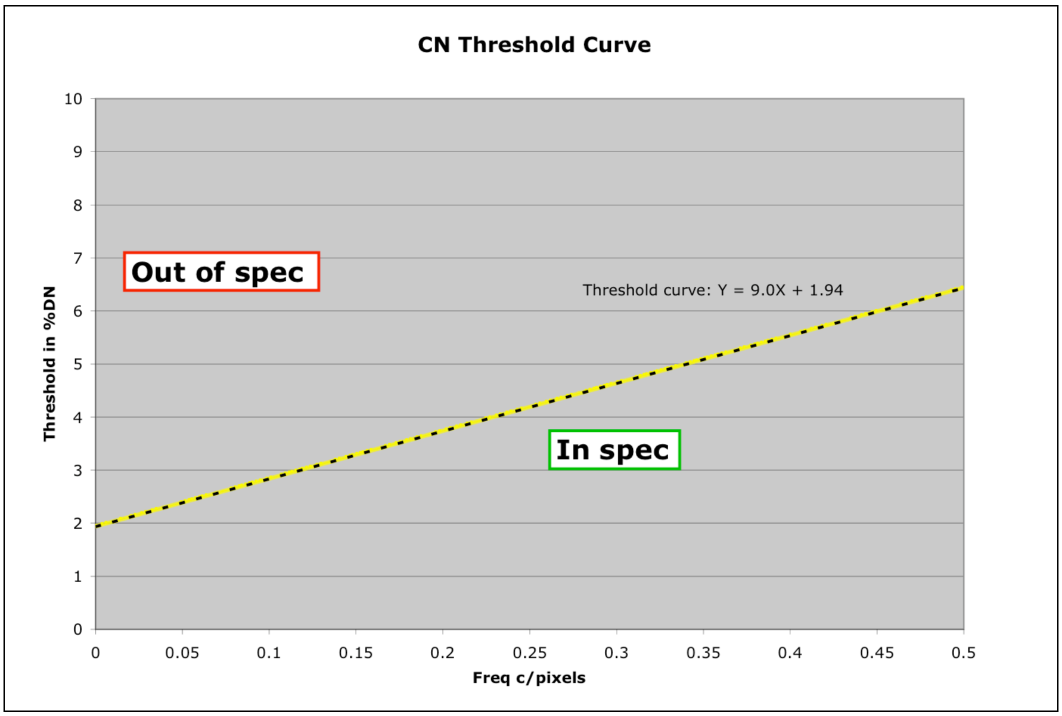


Figure 5.6-2 Coherent Noise Threshold Curve

5.6.3 Saturation Radiances

The OLI instrument shall detect, without saturating, signals up to the L_{max} as shown in Table 5.6-2, starting 180 TBR days after commissioning.

Note: For bands 1-8, this corresponds to the radiance reflected off of a Lambertian target of 100% reflectance illuminated by the sun at a solar zenith angle of 22.5°.

5.6.4 Polarization Sensitivity

The OLI instrument polarization sensitivity, as defined by the linear Polarization Factor (PF), shall be less than 0.05, where PF = (Imax-Imin) / (Imax+Imin).

5.6.5 Radiometric Stability

Over any time period up to 16 days, after radiometric correction per 5.3.1.2, with one set of gain coefficients that were determined prior to the 16 day period, the scene averaged OLI instrument data for radiometrically constant targets with radiances greater than or equal to $L_{-typical}$ shall not vary by more than plus or minus 1% (95% or 2 sigma confidence interval) of measured radiance.

Over any time period between 16 days and 5 years, after radiometric correction per 5.3.1.2, the scene-averaged OLI instrument data for radiometrically constant targets with radiances greater than or equal to $L_{-typical}$ shall not vary by more than plus or minus 2% (95% or 2 sigma confidence interval) of target radiance.

Between 2 adjacent WRS-2 scenes, the scene-averaged OLI instrument data for radiometrically constant targets with radiances greater than or equal to $L_{-typical}$ shall not differ by more than 0.5% of target radiance.

5.6.6 Image Artifacts

5.6.6.1 Bright Target Recovery

Bright target recovery requirements apply when an image pixel is exposed to a radiance level of up to 1.5 times that of the saturation radiance (Table 5.6-2). Any pixel outside the 7 x 7 pixel region around that pixel shall not have its signal change by more than 1% of its radiance for bands 1-7 and 9 and by more than 2% for the panchromatic band. This requirement only applies when the pixels outside the 7 x 7 region are observing radiances at or above $L_{typical}$.

5.6.6.2 Detector-to-Detector Crosstalk

When any region of detectors is illuminated by radiance levels less than the saturation level, the signal on any other detector that is more than ten detectors away from the illuminated region shall not change by more than 1% of the affected detector's radiance. This requirement only applies when the receiving detectors' radiance is at or above $L_{typical}$ and after radiometric correction per 5.3.1.2.

Note: Detector-to-detector crosstalk addresses artifacts caused by electrical and optical crosstalk between two detectors.

5.6.7 Dead, Inoperable, and Out-of-Spec Detectors

5.6.7.1 Dead or Inoperable Detectors

Less than 0.1% of all detectors shall be dead or inoperable.

Note: dead or inoperable detectors may be removed from any performance averages and standard deviations for determining compliance to performance specifications.

5.6.7.2 Dead or Inoperable Detectors per Band

Less than 0.2% of the detectors in any spectral band shall be dead or inoperable.

5.6.7.3 Adjacent Dead or Inoperable Detectors

There shall be no across track adjacent dead or inoperable pixels.

5.6.7.4 Out-of-Spec Detectors

Less than 0.25% of the operable detectors in any spectral band shall fail to meet one or more performance requirements.

Note: Out-of-spec detectors may be removed from any performance averages and standard deviations for determining compliance to performance specifications.

5.7 LDCM Geometric Precision, Geolocation, and Cartographic Registration

The following sections detail the LDCM image geometric accuracy requirements that must be achieved when the correction algorithms provided in accordance with section 5.3 of this specification are applied to LDCM mission data to produce a scene product. The specific correction algorithms that apply to each geometric imagery requirement are shown in table 5.7-1.

Table 5.7-1 Image Requirement to Processing Algorithm Verification Mapping

	5.3.1 Radiometric Correction	5.3.2.1 Ancillary Data Processing	5.3.2.2 Line-of-Sight (LOS) Model Creation	5.3.2.3.1 LOS Projection to WGS84 Ellipsoid Surface	5.3.2.4 LOS Model Precision Correction	5.3.2.3.2 LOS Projection to Terrain Surface	5.3.3 Image Resampling
5.7.1 Band Registration Accuracy	X	X	X	X	X	X	X
5.7.2 Image Registration Accuracy	X	X	X	X	X	X	X
5.7.3Geodetic Accuracy	X	X	X	X			X
5.7.4 Geometric Accuracy	X	X	X	X	X	X	X

5.7.1 Band-to-Band Registration Accuracy

Corresponding pixels from the spectral bands in LDCM data that have been geometrically corrected including compensation for the effects of terrain relief shall be co-registered with an uncertainty of 4.5 meters or less in the line and sample directions at the 90% confidence level.

5.7.2 Image-to-Image Registration Accuracy

Two LDCM data sets of the same area, acquired on different dates, that have been geometrically corrected, including compensation for the effects of terrain relief, shall be capable of being co-registered by with an uncertainty less than or equal to 12 meters**,** in the line and sample directions at the 90% confidence level when image-to-image correlation is applied to data from the same spectral band. This requirement applies to data from all spectral bands except band 9.

5.7.3 Geodetic Accuracy

5.7.3.1 Absolute Geodetic Accuracy

The pixels for targets at the Earth's topographic surface in geometrically corrected LDCM data shall be located relative to the WGS84 geodetic reference system, G1150 or current version, with an uncertainty less than or equal to 65 meters (90% circular error*)*, excluding terrain effects. This specification applies to the horizontal error of ground control points measured in the processed image, after compensation for control point height.

5.7.3.2 Relative Geodetic Accuracy

The pixels for targets at the Earth's topographic surface in geometrically corrected LDCM data shall be located relative to the WGS84 geodetic reference system, G1150 or current version, with an uncertainty less than or equal to 25 meters (90% circular error), excluding terrain effects, over a WRS-2 scene, after the removal of constant offsets. This specification applies to the standard deviation of ground control points measured in the processed image, after compensation for control point height.

5.7.4 Geometric Accuracy

The pixels for targets at the Earth's topographic surface in LDCM data that have been geometrically corrected, including pointing refinement using ground control and terrain compensation using digital elevation data, shall be located relative to the WGS84 geodetic reference system, G1150 or current version, with an uncertainty less than or equal to 12 meters (90% circular error), including compensation for terrain effects.

5.8 In-Flight Calibration

The OLI instrument shall have on-board calibration systems that provide sufficient data with precision and accuracy to meet the calibration and stability requirements of the OLI instrument or as described in this document.

5.8.1 Reflective Band Calibration Sources

Sources for the in-flight calibration shall include celestial objects including both the sun and the moon, and on-board sources such as lamps.

5.8.2 Reflective Band On-board Calibration Systems

The calibration systems shall at a minimum include:

a.) A full aperture full system pressed and sintered PTFE (space-grade Spectralon™ or equivalent with existing space flight response characteristics) solar diffuser with the capability to assess the diffuser deployment orientation stability with time.
b.) The solar diffuser shall be designed to perform calibrations at a solar zenith angle, (θ_S), of no greater than 60° and a view zenith angle, (θ_V), of no greater than 45°, see Figure 5.8-1.
c.) The diffuser shall be protected from solar illumination when not in use.

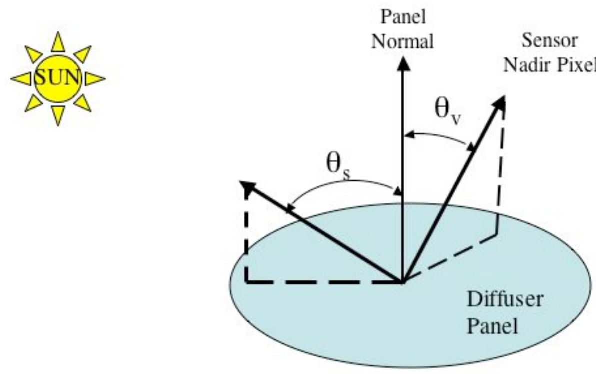


Figure 5.8-1 Diffuser Panel Relative Geometry

d.) A calibration source with at least three selectable lamps, each of which illuminates all detectors and stimulates bands 1-9. The lamps shall be operable in constant irradiance and constant current modes. This calibration source shall have at a minimum an independent total optical power output monitor.

e.) A device by which the dark signal of all the detectors can be monitored without requiring non-nominal sensor operations.

f.) Permanently masked dark detectors for each sensor chip assembly to generate sufficient data to track bias stability during daylight acquisitions for each band

g.) A device by which the linearity of the OLI instrument with respect to radiance can be characterized on orbit

h.) A source designed to be stable between prelaunch and on orbit environments and throughout launch. This source shall be exercised prelaunch and postlaunch to test the transfer to orbit the stability of the OLI instrument.

Note: Use of a single calibration device to meet more than one of these requirements is not excluded.

6 Structural and Mechanical Systems

The LDCM OLI structure shall be of sufficient strength and stiffness to maintain structural integrity and withstand all ground testing, handling, transportation, launch, launch vehicle separation, and mission orbit environments.

The LDCM OLI structure shall provide structural support and orientation.

The LDCM OLI structure shall provide a mounting interface for the OLI to the LDCM Spacecraft.

The LDCM OLI structural and mechanical interface shall accommodate manufacturing tolerance, structural, and thermal distortions.

The LDCM OLI structural system shall provide an external optical alignment device.
Rationale: The OLI instrument needs to be co-aligned with the spacecraft inertial reference system and with the Thermal InfraRed Sensor.

The LDCM OLI mechanical alignment device shall be aligned to the optical axis of the OLI to less than 6.75 [TBC] micro-radians, 3-sigma for each axis.

The LDCM OLI mechanical alignment shall be internally stable to less than 6.75 [TBC] micro-radians, 3-sigma for each axis over the full thermal operational design temperature range over a 16-day observation cycle.

Rationale: The alignment stability of the OLI instrument is the single most critical mechanical design challenge. Stability induced alignment errors can not be back out of the on-orbit calibration data.

The LDCM OLI mechanical system shall provide a gaseous purge fitting.
Rationale: To allow a positive dry nitrogen gas purge within the OLI during all stages of instrument and satellite integration, test, shipment, launch site processing, and while on the launch pad up to T-0.

The LDCM OLI shall use a body reference coordinate system that is defined as a right-hand, orthogonal, body fixed, XYZ coordinate system with the +Z axis aligned with the OLI instrument optical axis. The origin is located at the OLI to Spacecraft Bus interface plane.
Rationale: This orientation provides that when the observatory is in a nominal earth pointing attitude, the +Z axis points towards the Earth sub-satellite point.

The LDCM OLI shall provide easy access for the cleaning of all critical telescope optical surfaces during all phases of Integration and Testing (I&T) and the launch site.
Rationale: Easy access is defined as the ability to clean the telescope optical surfaces in a single I&T shift without major sensor system disassembly or de-integration from the OLI GSE or de-integration of the OLI from the spacecraft bus.

7 Thermal Control

The LDCM OLI shall be thermally safe for continuous operations in all nominal operational modes.
Rationale: This does not include the OFF Mode.

The LDCM OLI shall maintain its subsystems within their survival temperature range when the OLI is in Survival Mode.
Rationale: During Safe Hold the observatory subsystems including instruments are allowed to thermally drift in order to minimize power consumption.

The LDCM OLI shall maintain subsystems within their design operational temperature range for nominal operational modes except for Decontamination Mode.
Rationale: During de-contamination of the FPA or other elements it is conceivable that components could exceed their design operational temperatures.

The LDCM OLI shall provide heaters required for precision temperature control.

The LDCM OLI precision temperature control heaters shall be located within the OLI, controlled by the instrument electronics and using power from the overall OLI power budget.

The LDCM OLI shall keep the imaging sensor thermally stable over a 16-day observation period within its design temperature range, while in the operational modes.
Rationale: Keeping the imaging sensor thermally stable will have a direct effect on quality of image data. It is anticipated that the OLI instrument will have a long thermal constant and observing time could be lost if its temperature is permitted to drift.

The LDCM OLI operational thermal range shall be reprogrammable on orbit.

The LDCM OLI survival heaters shall be on a power circuit independent of the OLI instrument.
Rationale: OLI survival heaters must be powered when the rest of the instrument is powered off. Survival heaters are assumed on while OLI is in the OFF mode.

8 Electrical System

The LDCM OLI shall provide short circuit protection or current limiting for each power circuit coming into the instrument.

The LDCM OLI shall provide protection from over voltage and under voltage conditions for power coming into the instrument.

The LDCM OLI shall be designed to operate from a 28 +/- 6 Volt direct current power subsystem.

The LDCM OLI shall have an orbit average power consumption not to exceed 250 Watts [TBC].

The LDCM OLI shall have a peak power consumption not to exceed 450 Watts [TBC] for a period of 10 minutes [TBC] per orbit.

The LDCM OLI shall have a survival power consumption not to exceed 100 Watts [TBC] orbit average.

9 Flight Software

9.1 General

The LDCM OLI flight software shall be reprogrammable on orbit (excluding FPGAs and ASICs).
Rationale: This requirement is not intended to have embedded flight software in FPGA or permanently code state machines changed on-orbit. However, programmable FSW contained in sensors, actuators and other subsystem devices are included in this requirement.

The LDCM OLI shall possess sufficient non-volatile memory to contain two entire copies of the OLI flight software image at launch.

The LDCM OLI shall monitor flight software tasks or functions to detect for infinite loops or "hung" processes.

The LDCM OLI flight software shall protected against SEUs and other memory and processor errors.
Rationale: This can be done through the use of design features such as memory error detection and correction (EDAC), periodic software refresh of critical hardware registers, processor and register majority voting, watchdog timers, etc.

The LDCM OLI flight software shall verify the validity of all memory areas.
Rationale: To ensure that valid data/ instructions, etc. are in use. This task should run with a high enough frequency to fix environment induced bit flips.

The LDCM OLI flight software shall detect and correct single bit memory errors.
Rationale: Because bit flips happen.

The LDCM OLI flight software shall detect and report multiple bit errors in memory.
Rationale: Because bit flips happen and not all errors can be corrected.

The LDCM OLI flight software shall provide the capability to monitor the resource utilization by software subsystems or critical functions.
Rationale: To ensure that margins are maintain over the development life of the software.

The LDCM OLI flight software shall make resource utilization monitors available for downlink in telemetry.
Rationale: To verify functions are running smoothly and with expected CPU utilization.

The LDCM OLI stored commands shall be unaffected by a flight software upload.
Rationale: S/W patches should be independent of instrument command queue.

The LDCM OLI flight software tasks shall have a defined execution priority.
Rationale: Because critical tasks need to execute before non-critical tasks.

The LDCM OLI flight software shall store the version identifier of reprogrammable software onboard.

The LDCM OLI firmware shall store the version identifier of the embedded software onboard.

The LDCM OLI flight software shall maintain a mapping of table name to memory address location.

The LDCM OLI flight software shall be capable of updating memory table locations through ground command table names.

The LDCM OLI flight software shall provide the capability to load any location of on-board memory by referencing its physical memory address.

The LDCM OLI flight software shall be capable of dumping any location in program memory.
Rationale: to support debugging efforts and provide additional telemetry points which may have been unanticipated at development time

The LDCM OLI flight software shall be capable of dumping the entire memory of on-board processors.
Rationale: To support debugging efforts and provide telemetry state of the on-board flight software

The LDCM OLI flight software memory dump capability shall not disturb nominal execution of the flight software.

Rationale: This requirement is not to effect the on-going observatory operations or software processes. This requirement should only effect (replace or supplement or use excess wideband data) capability to get the memory dump telemetry on the ground.

The LDCM OLI shall implement independent time-based (watch-dog timer) monitoring circuits.
Rationale: On-board processors should use hardware "watch dog" timers, or some hardware implemented system independent of the CPU to interrupt stuck software.

9.2 Event Logging

The LDCM OLI flight software shall time tag events logged in telemetry with an accuracy of 250 milliseconds or less.
Rationale: A reported event would contain information on the source processor, flight software task or function, severity level, message identifier and informational string that identifies the cause. The event messages capture anomalous events, redundancy management switching of components and important system performance events and warm and cold restarts to the accuracy of command execution.

The LDCM OLI flight software shall report all event messages in the observatory housekeeping telemetry.

9.3 Initialization

The LDCM OLI shall preserve contents of the event log after rebooting or power cycling a processor.

9.3.1 Cold Restart

The LDCM OLI shall execute a cold restart of a processor's software from Read Only Memory in response to a ground command.
Rationale: This is a reboot of the flight software instruction set loaded from the non-volatile on-board memory (EEPROM, PROM, etc.) and does not require a power-on reset.

The LDCM OLI flight software shall execute a Cold Restart initialization process when starting execution from a hardware reset.

The LDCM OLI flight software shall execute a restart of a processor's software from Read Only Memory following a power cycle or hardware reset.
Rationale: This is a complete reboot of the flight software loaded from the non-volatile on-board memory (EEPROM, PROM, etc.).

The LDCM OLI flight software shall default to a known telemetry configuration following a Cold Restart.

The LDCM OLI flight software shall execute a Cold Restart when the number of failed Warm Restart attempts equals or exceeds a predetermined value.

9.3.2 Warm Restart

The LDCM OLI flight software shall execute a Warm Restart initialization processing when restarting the OLI flight software from software command.

The LDCM OLI flight software Warm Restart initialization shall preserve command processing statistics and memory tables and command sequences that were previously uploaded.

9.4 Failure Detection, Protection and Correction

The LDCM OLI shall automatically detect and report in telemetry hardware and software out of limit and fault conditions.

The LDCM OLI subsystems that perform self diagnostics shall report the results in telemetry.

The LDCM OLI subsystems that support self diagnostics shall accept ground commands to run diagnostics and report the results in telemetry.

Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

The LDCM OLI shall reject invalid commands.

The LDCM OLI shall report rejected commands in housekeeping telemetry.

9.5 Hardware Commands

The LDCM OLI watchdog timer shall be enabled or disabled by a hardware pulse command.
Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

The LDCM OLI onboard processors shall be capable of being reset via hardware pulse command.
Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

10 Solid State Recorder (SSR)

10.1 Data Flow

The LDCM I-SSR shall assign unique CCSDS Packet Application Identification by Spectral Band of OLI and TIRS data output.
Rationale: Band specific organization is more conducive to compression and is how data is handled on the ground.

The LDCM I-SSR shall assign unique CCSDS Packet Application Identification to the ancillary data.
Rationale: Packet by source is more conducive to how data is handled on the ground.

The LDCM I-SSR shall assign unique CCSDS Packet Application Identification by each instrument housekeeping source and uniquely for the spacecraft bus housekeeping source.
Rationale: Packet by source is more conducive to how data is handled on the ground.

10.2 Operational Modes

The LDCM I-SSR shall at a minimum have the following operational modes.

Rationale: The SSR modes are identified here to provide consistent use through the requirements documents. The contract must map their existing modes to these modes to ensure compliance but does need to invoke these modes by name.

10.2.1 Power Off Mode

The LDCM I-SSR shall have a power off mode where all LDCM I-SSR functions and elements are powered down, except for survival heaters (as required).
Rationale: There is no requirement to retain stored image and ancillary data while the LDCM I-SSR is powered off. Survival heater power is provided directly by the spacecraft bus.

10.2.2 Power On Mode

The LDCM I-SSR power on mode shall provide an orderly start up and configuration of the LDCM I-SSR processing, control, and memory electronics, including execution of internal diagnostics and activation of the SSR housekeeping telemetry (TLM) interface to the spacecraft bus.
Rationale: The SSR will start flowing its HK data directly to the bus over the spacecraft bus to SSR HK telemetry interface.

The LDCM I-SSR shall be powered independently from any other LDCM Observatory subsystem or instrument.
Rationale: The SSR will need to be checked out, tested, diagnosed independently from the instruments and other equipment.

10.2.3 Standby Mode

The LDCM I-SSR shall autonomously enter standby mode from the power on mode after successful completion of all diagnostic checks.

The LDCM I-SSR shall retain indefinitely, unless power is cycled off, all data stored in the LDCM I-SSR storage memory.

The LDCM I-SSR shall enter Standby mode either from power on mode or from one of the other operational modes based on commands received from the spacecraft bus.

10.2.4 Self Test Mode

The LDCM I-SSR shall implement a Self Test Mode.

The LDCM I-SSR Self Test Mode shall generate a predetermined Self Test image data pattern that is applied to each instrument interface at their respective full data rate.

The LDCM I-SSR Self Test data pattern shall be stored up to the full available capacity of the LDCM SSR.

The LDCM I-SSR shall be capable of playing back stored image or test data to the downlink output interface while simultaneously recording the test data.

10.2.5 Downlink Test Mode

The LDCM I-SSR shall implement a Downlink Test Mode.

The LDCM I-SSR Downlink Test Mode shall generate a pseudorandom noise (PN, PRN) pattern of 32,767 bits length (PN15, 2^{15}-1) to the downlink output interface for bit error rate (BER) testing of each downlink channel.

10.2.6 Operational Mode

The LDCM I-SSR shall implement an Operational Mode.

The LDCM I-SSR shall concurrently record real-time data and playback stored data.
Rationale: this capability can be selected in any permutation

The LDCM I-SSR shall output up to two unique and concurrent playback streams of Mission Data.
Rationale: Simultaneous playback from two locations within the SSR. This would consist of band ordered image data plus the ancillary data that goes with it.

The LDCM I-SSR shall output 1 real-time Mission Data stream concurrently with the two concurrent playbacks of Mission Data.
Rationale: Simultaneous real-time pass through and playback from two memory locations within the SSR.

The LDCM I-SSR shall playback CFDF files based on ground schedules.
Rationale: The ground will establish playback schedules including scheduling some files for priority playback.

10.2.7 Safe Mode

The LDCM I-SSR shall implement a Safe Mode.

The LDCM I-SSR shall autonomously enter Safe Mode when exiting from Power On Mode or Self-Test Mode and an anomaly has been detected.

Rationale: Entered Safe Mode whenever non-survival (i.e. data storage, configuration or memory management errors) hardware or software errors occur.

The LDCM SRR shall remain powered on, with telemetry available and provided to the Spacecraft Bus telemetry interface when in Safe Mode.
Rationale: SRR buffers/registers/memory should be accessible as required (for diagnostic dumps).

10.3 Data Storage

The LDCM I-SSR total capacity shall consist of the summation of the following four requirements during any 24 hour period.
Rationale: The total data that can be stored at any time includes all image data + all calibration data taken in the last 24 hours + the corresponding ancillary data + the observatory housekeeping data for the last 72 hours.

The LDCM I-SSR shall ingest and store the equivalent of 9 reflective bands of 400 individual WRS-2 scenes.
Rationale: The SSR will serve as the primary mass storage device on the observatory. It should be sized to support all systems needing mass storage. This is the reflective band sensor, OLI.

The LDCM I-SSR shall ingest and store the equivalent of 2 thermal bands of 400 individual WRS-2 scenes.
Rationale: This is the TIRS data storage

The LDCM I-SSR shall ingest and store all ancillary data associated with the OLI and TIRS image collection.

The LDCM I-SSR shall ingest and store all lunar and solar calibration data.

The LDCM I-SSR shall use Error Detection and Correction (EDAC) to ensure data stored on the SSR has no more than one error in 10^{12} bits per 24 hour period.
Rationale: The bit error rate is to limit the number of bad bits prior to transfer to the downlink interface.

The LDCM I-SSR shall ingest and store 1,036.8 kbits of observatory housekeeping data.
Rationale: The 72 hours of observatory HK data is based on 4kbps for 72 hours =

The LDCM I-SSR shall store data in the CCSDS File Delivery Format (CFDP) in compliance with CCSDS 727.0-B-3.

The LDCM I-SSR shall demultiplex OLI image data into unique CCSDS formatted packets which contain separate and unique band sequential OLI image data on 5 second [TBC] intervals.

The LDCM I-SSR shall concatenate together into a single file all Mission Data packets of the same time interval into a CFDP file for storage.
Rationale: This requirement does not preclude the OLI from performing some or all of the band sequential organization and CCSDS formatting of image and ancillary data or compression of the image data.

The LDCM I-SSR shall assign a unique file header that contains a unique ground defined identifier for the file name, a unique timestamp accurate to 1msec accuracy relative to the OLI time reference, along with file length, sequencing and configuration information with respect to the formatting and processing modes of the LDCM I-SSR and OLI.

The LDCM I-SSR shall provide a means to assign file attributes that denotes protected data, test data, and/or data that can be overwritten.

The LDCM I-SSR shall include file attributes when a directory listing is requested.

The LDCM I-SSR shall have the capability to ingest and store LDCM Spacecraft generated data independently of image operations.
Rationale: Ancillary data, observatory HK data generated by the spacecraft will be available when the OLI is doing something besides imaging. Therefore this data should be stored whether imaging or not imaging.

The LDCM I-SSR shall have the capability to ingest and store LDCM Instrument generated Mission Data independently.
Rationale: The LDCM instruments will at time operate independently of each other and their mission data still needs to be stored.
LDCM I-SSR

10.4 Data Playback

The LDCM I-SSR shall have the capability to playback LDCM Spacecraft generated data independently of image operations.
Rationale: Playback data acquired during periods when there were no imaging operations

The LDCM I-SSR shall ensure a data rate not to exceed 230 megabits / second for each physical downlink telemetry stream.
Rationale: The current capability of X-band transmissions systems is around 230 megabits / sec. All the data needs to come down on a single X-band channel. Therefore OLI instrument data may need to be compressed. Sum the data on all the virtual channels assigned to a physical channel.

The LDCM I-SSR shall playback requested data based upon commands received via the LDCM Observatory command and control interface.

The LDCM I-SSR shall support multiple playbacks of stored data.

The LDCM I-SSR shall playback data corresponding to file names specified in a command string at the time specified in the command string.

The LDCM I-SSR shall playback data corresponding to physical memory address locations specified in a command string at the time specified in the command string.

The LDCM I-SSR shall be able to multiplex image and ancillary CCSDS packets into a physical CFDP data stream.

The LDCM I-SSR shall ensure that complete CFDP files are provided to the downlink interface when a playback command is executed.

The LDCM I-SSR shall always provide incrementally increasing Virtual Channel Data Units (VCDU) counts, even when a partial mission data file is being read out.
Rationale: Repeatedly is when portions of a file must be sent a second or third time to recover a partial playback on the first playback/readout attempt.

The LDCM I-SSR shall always output the LDCM Instruments' data and their corresponding ancillary data together.

The LDCM I-SSR shall insert fill CADUs and fill packets as required to maintain a synchronous, constant data rate output to the LDCM Observatory downlink interface.
LDCM I-SSR
The LDCM I-SSR shall accept commands to designate any single or set of data files as protected.
Rationale: To protect priority files or other data this would disable the automated file overwrite feature.

The LDCM I-SSR shall accept commands to designate any single or set of data files as available for overwrite.
Rationale: This allows the ground to go back and remove the protection on files or other data.

The LDCM I-SSR shall, on command, provide a listing or directory of its file system including key file attributes.

The LDCM I-SSR shall transfer file directory listings as a separate CCSDS packet type via the wideband interface based on ground command.

The LDCM I-SSR shall transfer file directory listings as a separate CCSDS packet type through the SSR control interface via the S/C telemetry path to the ground based on ground command.
Rationale: Ground selectable transfer of the File Directory. This allows getting the file directory but not using the X-band system.

The LDCM I-SSR shall provide the capability to change the attributes of stored data from "protect" to "overwrite" to allow the reuse of memory space.

The LDCM I-SSR shall overwrite data from oldest to youngest.
Rationale: provide the capability to change the attributes of stored data from "protect" to "overwrite" to allow the reuse of memory space.

10.5 SSR Fault Detection and Correction

The LDCM I-SSR shall have autonomous internal fault detection and correction capabilities to provide notification of anomalous operating conditions through the command and control interface.

10.6 SSR Simulator

There's an SSR simulator…

11 Command & Data Handling

11.1 General

The LDCM OLI shall be capable of maintaining the health and safe operations of all elements of the instrument without ground support.

The LDCM OLI shall continuously monitor its health and safety.

The LDCM OLI shall report the health and safety of the instrument to the spacecraft.

The LDCM OLI shall time tag OLI instrument data with an accuracy relative to the LDCM Observatory time reference of 150 microseconds or less, 3-sigma.
Rationale: To ensure that the image data can be synchronized with the ancillary data the two time references should be accurate to each other within 50msecs.

The LDCM OLI will receive a one pulse per second from the LDCM spacecraft for time synchronization.

The LDCM OLI reference time shall be accurate to within 50 microseconds or less, 3-sigma of each LDCM Observatory 1-second timing pulse.

11.2 Telemetry

The LDCM OLI shall provide sufficient telemetry to ensure proper control and monitoring of OLI health and safety, and to identify anomalous conditions.
Rationale: For proper insight into the state of health and on going instrument activities

The LDCM OLI shall provide onboard storage for at least 4 [TBC] different operator defined telemetry stream formats.
Rationale: Unique telemetry streams are likely to be needed to support the various phases of instrument operations, commissioning, operations, diagnostics, etc.

The LDCM OLI shall provide the capability to select a telemetry stream definition from onboard storage via a single command.

The LDCM OLI shall report the command identifier in housekeeping telemetry when executed.
Rationale: When OLI executes a command this information should be written off into the HK telemetry.

The LDCM OLI shall generate and transmit real-time instrument housekeeping data to the LDCM spacecraft.
Rationale: Real-time HK data is needed to monitor and control the instrument.

11.3 Command Capability

The LDCM OLI shall accept and execute discrete / hardware pulse commands in real time only.

The LDCM OLI shall be capable of processing real-time commands while concurrently executing long-duration commands.
Rationale: commands such as on-board processor uploads, imaging may take several minutes and once these processes have started the instrument should be able to continue processing normal functions.

The LDCM OLI shall be capable of receiving flight software loads across multiple contacts.

The LDCM OLI shall be capable of receiving flight software updates by patches at the function, unit or module level.

The LDCM OLI shall validate, process, and execute commands and data loads.

The LDCM OLI shall not execute a command that has failed validation.

The LDCM OLI shall report commands that fail validation in housekeeping telemetry.

The LDCM OLI shall have no command lockout.
Rationale: There is no command to lock-out or permanently disable the OLI instrument

The LDCM OLI shall be capable of accessing information from one or more separate data tables stored in onboard RAM through a single command.

The LDCM OLI shall be capable loading a parameter of a table without loading the entire table.

The LDCM OLI real-time command shall perform only one function, fully identified in the command data field establishing a known state and condition.
Rationale: Using toggle commands can leave the state of a switch, box, etc. unknown. It is better to have enables and disables be unique commands and not just toggle back and forth. A toggle commands would not be permitted as they do not fully define the final state.

The LDCM OLI shall execute a command at a frequency of at least 1 Hz [TBC].

The LDCM OLI shall have a command execution accuracy of 0.1 seconds [TBC].

12 Technical Resource Margins

The LDCM OLI shall use the following equation for margin calculations:
Margin (in percent) = 100% x (Available Resource-Estimated Resource) / Estimated Resource.
Rationale: The use of margins is intended to improve performance on mission level cost and schedule in addition to mission performance. This margin equation should be used for each technical resource.

The LDCM OLI shall use a maturity level to define required margins.
Rationale: By using the maturity level then new development items will be properly combined with heritage items when the total observatory is accounted.

The LDCM OLI technical resources shall have the following minimum resource design margins at the end of a component's development phase:

Resource	**Contract ATP**	**Mission Design Review (Phase A)**	**Preliminary Design Review (Phase B)**	**Critical Design Review (Phase C)**	**Pre-Environmental Design Review (Phase D)**
Mass	>30%	>25%	>20%	>15%	5%
Power (wrt End of Design Life Capacity)*	>30%	>25%	>15%	>15%	>10%*
Telemetry and Command Hardware Channels**	>25%	>20%	>15%	>10%	2%

Rationale:

*At launch there shall be 10% predicted power margin for mission critical and safe hold modes as well as to accommodate in-flight operational uncertainties.
** Telemetry and command hardware channels read data from hardware such as thermistors, heaters, switches, motors, etc.

The LDCM OLI flight software shall have the following minimum resource margins at the end of each development phase per processor:

Resources	**Mission Design Review (Phase A)**	**Preliminary Design Review (Phase B)**	**Critical Design Review (Phase C)**	**Pre-Environmental Design Review (Phase D)**
Central Processing Unit Utilization	50%	50%	40%	30%
Central Processing Unit Deadlines	50%	50%	40%	30%
Programmable Read-Only Memory	50%	30%	20%	5%
Electrically Erasable Programmable Read-Only Memory	50%	50%	40%	30%
Random Access Memory	50%	50%	40%	30%
Peripheral Component Interconnect (PCI) bus	75%	70%	60%	50%
1553 bus	30%	25%	20%	10%
Universal Asynchronous Receiver-Transmitter (UART)	50%	50%	40%	30%
Observatory Command Bus Throughput	50%	50%	40%	30%
LVDS	50%	50%	40%	30%

13 Launch Services

13.1 Payload Processing Facility Compatibility

13.2 Launch Site Support

13.3 Launch Vehicle

14 Science and Mission Requirements Document (SMRD) Traceability

To be supplied

15 Verification Cross Reference Matrix (VCRM)

To be supplied